Design of Insulated Buildings for Various Climates

TYLER STEWART ROGERS

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for Various Climates

By TYLER STEWART ROGERS
Director of Technical Publications, Owens-Corning Fiberglas Corporation

Assisted by
DR. PAUL A. SIPLE
Climatologist and Military Geographer, Department of the Army, General Staff

PROF. ELMER QUEER
Consultant on Heat Transmission and Vapor Control, State College, Penna.

HOWARD T. FISHER, A.I.A.
Consulting Architect and Industrial Designer

JOHN HANCOCK CALLENDER, A.I.A.
Consulting Architect, Southwest Research Institute

F.W. DODGE
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Foreword:

What we don't know can hurt us

If you believe old sayings like "Ignorance is bliss", or "What you don't know can't hurt you", this book is of no interest to you. According to these adages, our best buildings might be designed and constructed by ignorant men.

Architects, builders and building owners alike must keep themselves informed of new things, new ideas, new technology, or else their structures will be out of date before they are completed. In fact, many buildings constructed today are *ten* to *fifteen years* behind the knowledge released by scientists and research men specializing on building problems.

The main reason for this lag in the use of new knowledge seems to be that most of us are too busy with our daily affairs to read all the technical reports that are issued by the real experts. They are not popular literature; and they get very meager circulation. They certainly are not written in layman's lingo. And most research papers deal only with one aspect of a broad problem, making it difficult for practical folk to put two and two, and maybe three more, together to get the answers they need.

These observations at least are true in the field of building insulation practices. The building insulation industry began to get big over thirty years ago. When some of its products didn't seem to perform as well as expected—because, in the light of present knowledge, they were used incorrectly—many unsound ideas developed, and brought misunderstanding and distrust. But as far back as 1937 and 1938 scientists like Teesdale of the Forest Products Laboratory and Rowley of the University of Minnesota gave us all the essential facts we need to use building insulations properly. Not enough people know of their work, even today.

What people do not understand they dislike or fear. What they know well they like and use.

Knowing that building insulation materials, properly used, made a tremendous contribution to better buildings in comfort, operating economy and even in simpler housekeeping, I have undertaken in this book to bring you a distillation of the established technical knowledge, presented (I hope) in readable and useful form.

Since the first need is to make the subject easily understandable, the first part of this book deals with *principles*. Illustrations have been used extensively to explain how climate, the sources and movement of heat, the sources and behavior of moisture, and the use of structural ventilation all have a practical bearing on good building design.

Since the next need is to make it easy to apply these principles in daily building design and construction, the second part of the book deals with *practices*. Here I have used both illustrations and carefully calculated reference tables to simplify the correct design of roofs or ceilings, walls and floors for buildings in any climate of the United States and for any occupancy.

All this is the result of more than twenty years of interest in building insulations and constant study of the new developments that have appeared from many sources. The building industry owes much to the scientists and research workers who have widely extended our knowledge of sound design by their advanced studies. I am particularly indebted to them all, for I have drawn upon their work without the usual courtesy of credit footnotes or even a bibliography.

To make certain that my non-technical interpretations of their findings have been correctly translated I have had the invaluable guidance of two eminent authorities. Dr. Paul A. Siple, who has earned world-wide recognition as a climatologist and military geographer, has been my mentor on all aspects of climate relation to building design. Elmer R. Queer of State College, Pennsylvania, and E. R. McLaughlin (partners in their consulting practice) have both made important contributions to the knowledge of building insulations, vapor control and condensation by the work they have done at the Engineering Experiment Station of Pennsylvania State College.

It is difficult for a man who has long made a hobby of one subject to know where to draw the line between being too elementary and too technical in his explanations, so I have sought the counsel of Howard T. Fisher, A.I.A. and John Hancock Callender, A.I.A. Mr. Fisher's architectural practice is largely in major buildings. He is also an industrial designer and has an exceptional interest in building materials and methods. Mr. Callender has specialized—through research as well as practice—in the small house field. They have guided the development of this book to make it of maximum readability and daily usefulness to architects and builders.

In addition to the indispensable guidance of the four consultants whose contributions I have already defined, I acknowledge gratefully the participation of my staff assistants, Dale J. Alcorn, who coordinated the many elements and supervised production; Stanley J. Stachelek who calculated all of the tables and assembled the material for Part II; Walter S. Young, Jr., who prepared the rough layouts and supervised production of the many charts and diagrams; George Walter, who served as art director; Bruno Funaro, of the firm of Howard T. Fisher and Associates, Inc., who executed the many line drawings and details for illustrations; Mrs. Juanita Wright, my secretary, who relieved me of much correspondence and directed all the extensive typing involved; Richard Hoefer, publisher of *House Beautiful* Magazine, and Walter Taylor, Director of Research and Education of the American Institute of Architects, who permitted the publication of data initially prepared for *House Beautiful's* Climate Control program; the American Society of Heating and Ventilating Engineers, the Building Research Advisory Board and various other sources of valuable reference data; and the many friends, authorities, associates, artists and production men who together made this book possible.

TYLER STEWART ROGERS

Toledo, Ohio
June 21, 1951

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JOSEF MUENCH

HUBERT A. LOWMAN

Climate: *Affects our comfort ... and building design*

The wiggly lines on the opposite page form a composite picture of the temperature-climate of the United States. It is also a nearly perfect picture of the temperature-climate of the world because, according to Dr. Paul A. Siple, "the climate of the United States is so diverse that practically every type of world climate can be found represented in some section of our country".

"For some extremes," he notes, "such as the hottest temperatures and the greatest depth of snowfall, the United States possibly holds the world's record". Key West resembles the oceanic tropics; the Pacific Northwest is like Northern France and Great Britain; most of California is typical of the Mediterranean and of South Africa and New Zealand. The Southwest is comparable to the great deserts of Africa and Australia; even the Polar regions are amply represented from Mt. Rainier to Mt. Washington.

We live, as a Nation, with this great diversity of climates. We do not have to migrate, like the birds, to avoid the vagaries of nature, or to escape her capricious moods. Instead, we have learned to adapt ourselves to the extremes we experience almost everywhere, even to gain stimulation and relaxation from them in our vacation periods. As our scientific knowledge has expanded, we have also learned how to create and maintain "indoor climates" that provide comfort, protect health, conserve energy, and enhance our productivity. The latest developments in this area constitute the subject of this book.

A. DEVANEY, INC., N. Y.

We expect this in the North

. . . but not in Southern California

Climate: *We are always contending with Nature for comfort . . . or survival*

While extremes of temperature do not make a climate, they display Nature's power to disturb our lives. Snowstorms in the deep south and man-killing heat waves in our northern states, even in Alaska, remind us that very few areas are immune to Nature's less comfortable moods.

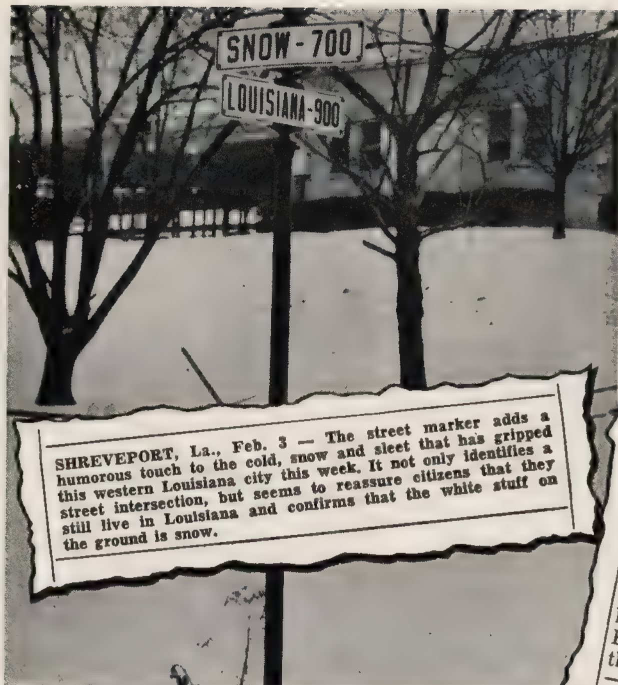
We can tolerate extreme temperatures for very brief periods but cannot survive them, without some protection, if they are protracted. Some of us take pride in our hardihood and our capacity to accept

EWING GALLOWAY, N. Y.

Because we can use extra clothing to shield us from cold, but cannot take off all our clothing in summer, it is excessive heat that causes most discomfort in normal U. S. living.

EWING GALLOWAY, N. Y.

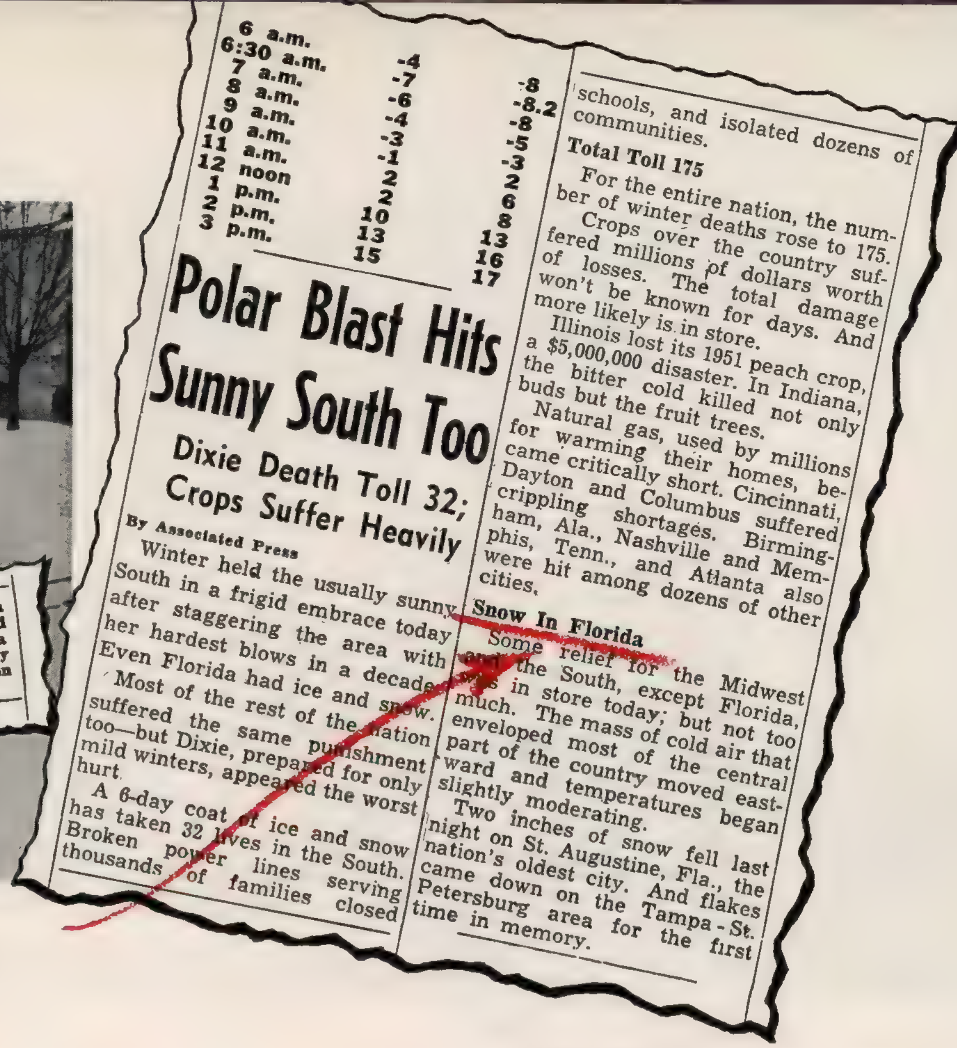
The siesta habit common to tropical climates where there is little relief from intense mid-day heat is not an American custom because our climate provides sufficient variety.



SHREVEPORT, La., Feb. 3 — The street marker adds a humorous touch to the cold, snow and sleet that has gripped this western Louisiana city this week. It not only identifies a street intersection, but seems to reassure citizens that they still live in Louisiana and confirms that the white stuff on the ground is snow.

WIDE WORLD PHOTO

or in Louisiana and Florida.



6 a.m.	-4	-8
6:30 a.m.	-7	-8.2
7 a.m.	-6	-8
8 a.m.	-4	-5
9 a.m.	-3	-3
10 a.m.	-1	2
11 a.m.	2	6
12 noon	2	8
1 p.m.	10	13
2 p.m.	13	16
3 p.m.	15	17

Polar Blast Hits Sunny South Too

Dixie Death Toll 32; Crops Suffer Heavily

By Associated Press

Winter held the usually sunny South in a frigid embrace today after staggering the area with her hardest blows in a decade. Even Florida had ice and snow.

Most of the rest of the nation suffered the same punishment too—but Dixie, prepared for only mild winters, appeared the worst hurt.

A 6-day coat of ice and snow has taken 32 lives in the South. Broken power lines serving thousands of families closed schools, and isolated dozens of communities.

Total Toll 175

For the entire nation, the number of winter deaths rose to 175.

Crops over the country suffered millions of dollars worth of losses. The total damage won't be known for days. And more likely is in store.

Illinois lost its 1951 peach crop, a $5,000,000 disaster. In Indiana, the bitter cold killed not only buds but the fruit trees.

Natural gas, used by millions for warming their homes, became critically short. Cincinnati, Dayton and Columbus suffered crippling shortages. Birmingham, Ala., Nashville and Memphis, Tenn., and Atlanta also were hit among dozens of other cities.

Snow In Florida

Some relief for the Midwest and the South, except Florida, was in store today; but not too much. The mass of cold air that enveloped most of the central part of the country moved eastward and temperatures began slightly moderating.

Two inches of snow fell last night on St. Augustine, Fla., the nation's oldest city. And flakes came down on the Tampa-St. Petersburg area for the first time in memory.

TOLEDO BLADE, FEB. 3, 1951

extreme cold or heat without complaint. Some of us take these discomforts as a matter of course, think nothing of them and do nothing to alleviate them.

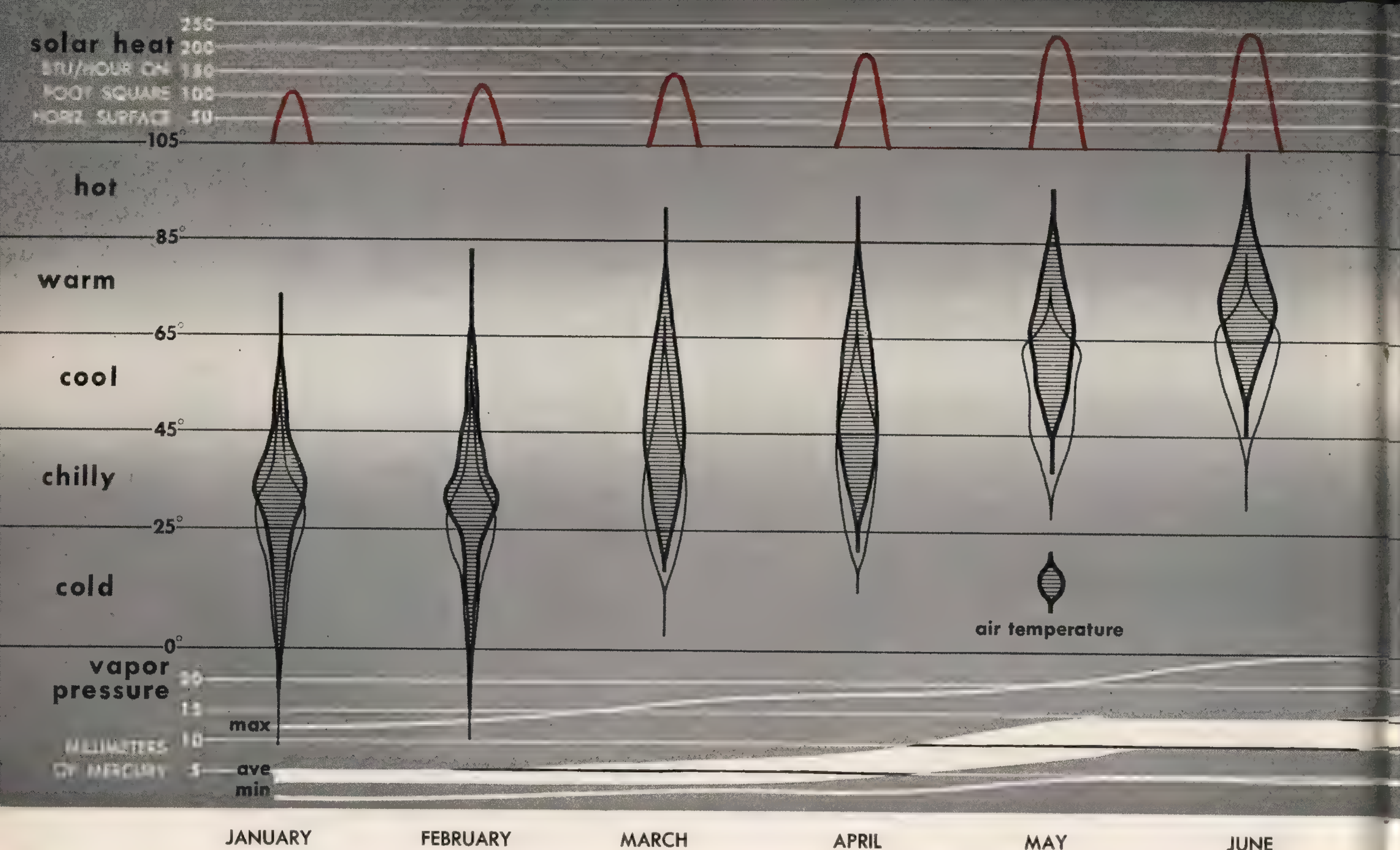
The rest of us, knowing that we can live better, produce more, have sounder health and enjoy greater comfort if our buildings shield us adequately from the weather, create an indoor "climate" that is as steady as the outdoor climate is changeable. *The degree to which we maintain comfort during extremes of weather is a measure of our standard of living.*

EWING GALLOWAY, N. Y.

Wind scoops used on sun-baked buildings in Hyderabad, Pakistan, catch breezes and force them downward by their own pressure as a means of cooling the hot interiors.

Thundershowers are Nature's contribution to summer comfort in areas where high humidity accompanies high temperatures. Winds, cloud shade and the cooling effect of rain from high altitudes all help.

EWING GALLOWAY, N. Y.



To illustrate how temperature and humidities are analyzed by months in the House Beautiful—A.I.A. "Climate Control" program, the mid-continent Kansas City-St. Louis area is shown above. Annual summaries of other areas are shown below.

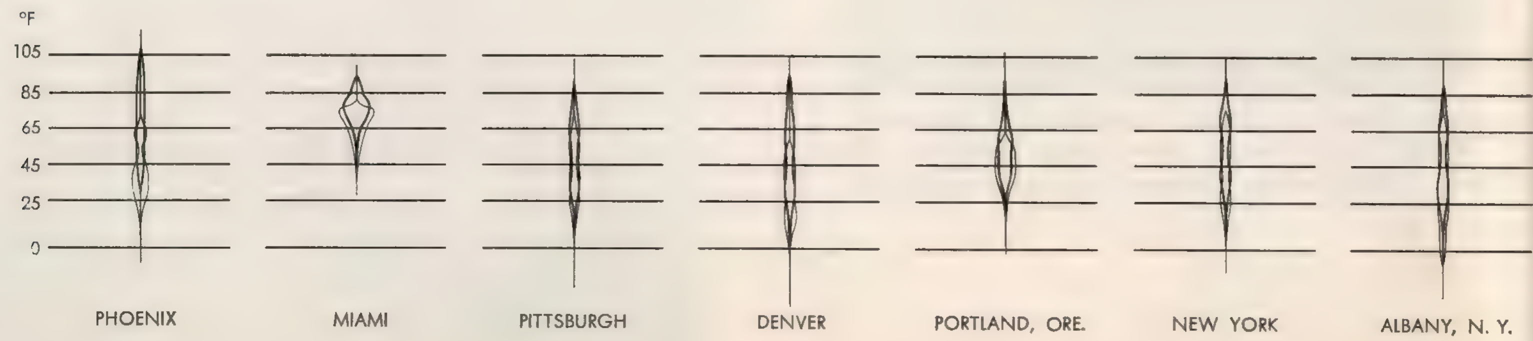
Climate: *How it is analyzed in charts and maps for practical design guidance*

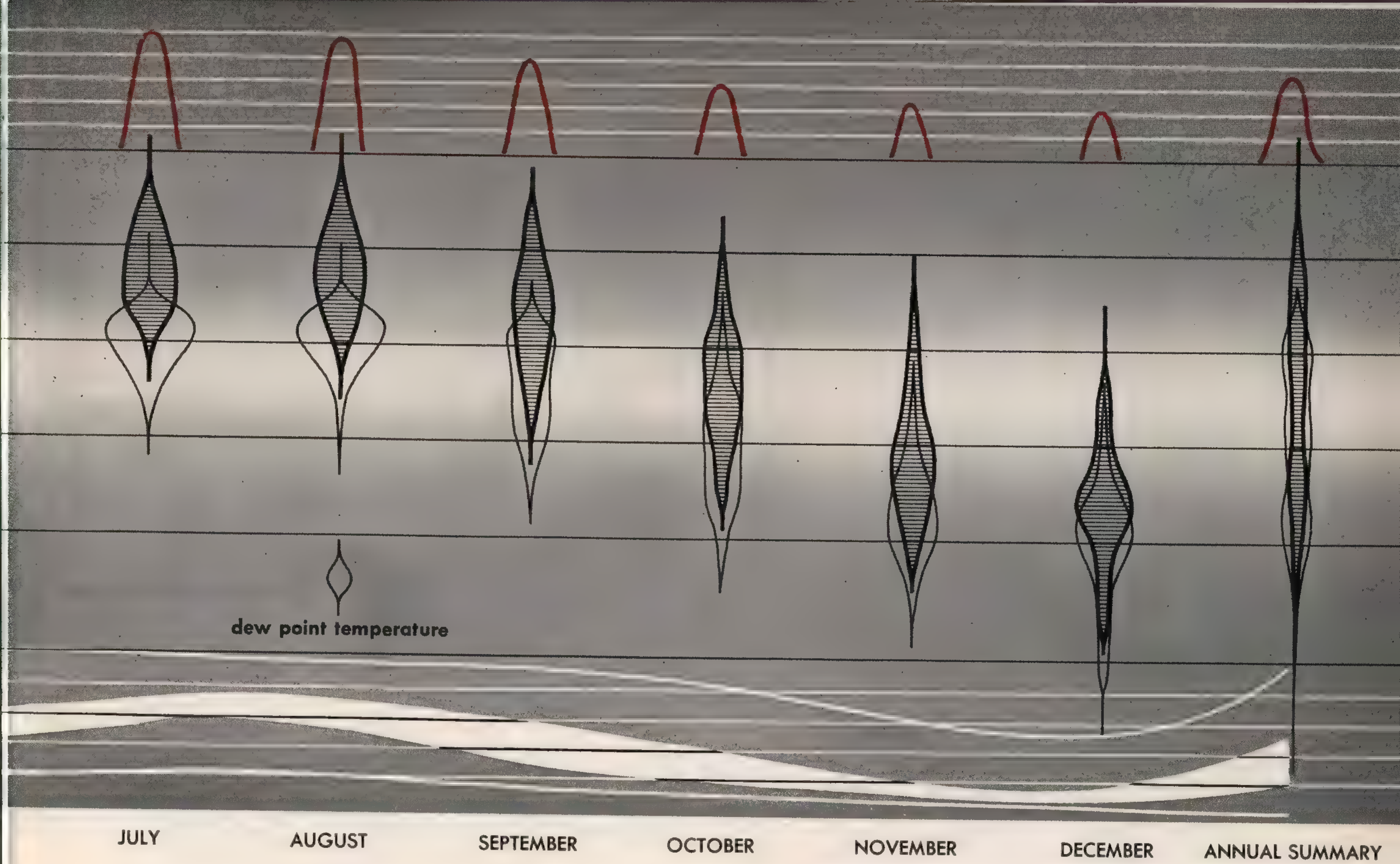
Climates are made up of many things: air temperatures, hot or cold; sun and sky-shine, warm to hot; fog, rain, snow and hail; winds, from zephyrs to cyclones; humidity (or vapor pressure); cloudy and sunny days; the position of the sun by seasons and hours of the day. All these, and each of them in different combinations with others, make up the climate where you live and work.

All of them *should* influence the design of your buildings and the materials you use. But here we will deal only with the elements of climate that affect the comfort and temperature-protective aspects of buildings. This includes air temperatures, sun and sky heat, humidity and winds.

The detailed temperature-humidity chart for the Kansas City-St. Louis area, above, and the annual summaries for 14 other cities, shown below, were prepared by Dr. Paul A. Siple and experts employed by *House Beautiful* Magazine in their Climate Control Project. The technical studies have been published in their entirety in the *Bulletin* of the American Institute of Architects. Reprints of these climate studies may be obtained from *House Beautiful* for 50 cents per copy per zone.

Dr. Siple has devised in these charts a simple way to express temperatures, not only by a thermometer, but by the calendar. In each chart the width of the shaded "leaf" represents the number of hours in the





month (or year) that have an average temperature that is measured up or down the vertical stem. Where the "leaf" is widest, you can read the temperature that prevails the longest. Where it is narrow, as at the extremities, the temperatures are experienced only for short periods, sometimes not more than an hour in many years of weather records.

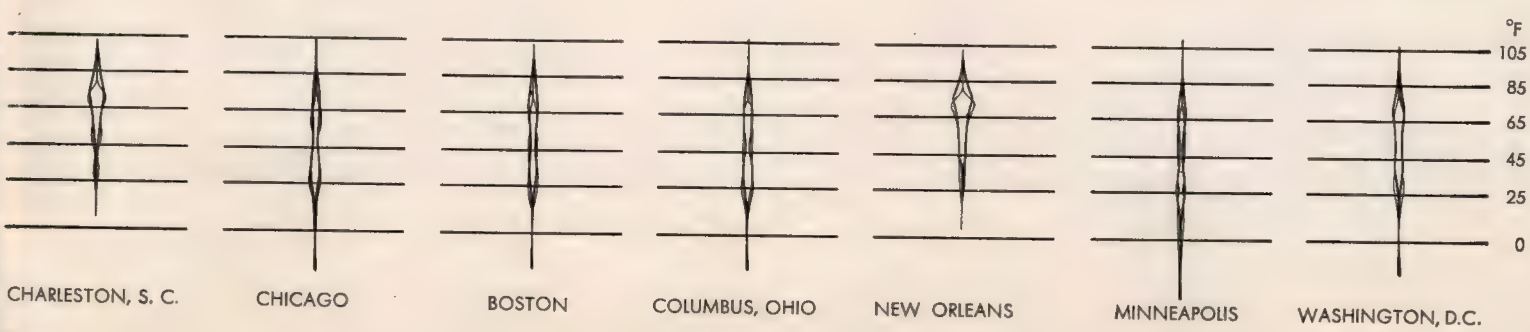
The unshaded "leaf" indicates the prevailing humidity by showing the actual dew-point temperatures of the outdoor air in the same manner. This dew-point is the temperature at which the air is saturated with moisture (water vapor) so that no more can be held. If the temperature is then lowered below this dew-point temperature, some of the water vapor will condense, *i.e.*, form dew, fog or rain. The important problem of vapor condensation in building construction is discussed in detail on page 35.

When the humidity climbs high with the temperature, as it does in the summer months, the atmosphere is muggy and very uncomfortable. When the humidity stays low, the air feels drier, and is usually more comfortable.

Across the bottom of the above chart are bands that show the humidity range expressed as vapor pressure. Vapor pressure is important in dealing with condensation problems and will be explained later. The wider center band shows the average range; the outer lines the extremes. High relative humidity, high temperatures and high vapor pressures go more or less together. Low temperatures, whether or not the relative humidity is high, show low vapor pressures.

Above, in the chart at the top of the page, are mountain-shaped curves that show how hot the sun gets on a flat roof. If the roof sloped toward the sun, the temperatures would be higher. Side walls vary in sun temperature according to the way they face, the time of day and the time of year, as will be discussed later.

The annual summaries for the fourteen other cities are given below. These reveal both a surprising general resemblance and some significant differences. Minneapolis temperatures extend through such a long range that spring, summer, fall and winter conditions exist for almost equal periods. New York and Boston are nearly alike; New Orleans has a long summer and short, mild winter. You will find it



fascinating to study the climate of your own locality in the complete A.I.A. *Bulletins* based on the *House Beautiful* Climate Control program.

These three factors—air temperature, solar heat, and relative humidity or vapor pressure, (plus wind which we shall consider later),—contribute importantly to the climate we try to create within buildings. Since we like to keep the indoor temperature level at 70° or closely thereabout, it takes only a glance at the charts on the previous two pages to see how much of the time Nature makes our task difficult. Part of the time it is too hot outdoors, part of the time it is too cold. Only in the 65° band is Nature cooperating for human comfort

The two maps below give the essential winter temperature facts about the United States. The *grey-shaded areas*, at the top, indicate cold zones; the *lower colored areas*, the warm zones; and the *white areas*, in between, the moderate zones. These are true temperature zones, based on nation-wide winter temperatures compiled and averaged for many years. *The solid black lines* that generally follow state boundaries establish the climate zones used by the Federal Housing Administration.

ZONE VALUES on the basic maps indicate geographical areas by temperatures. Zone I (cold) includes approximately all areas where the average minimum temperature (i.e., design temperature) is –20° F. or colder. Zone II (medium) embraces design temperatures roughly between 0° and –10° F. The remaining area, Zone III (warm) has design temperatures over 0° F.—(generally these areas actually have an average January temperature of 35° F. or above). These Zone-areas are convenient references used by F.H.A. and in later sections of this book for various design calculations.

OUTDOOR DESIGN TEMPERATURES are indicated below on the left map by the solid, wavy red lines. These design temperatures are the coldest temperatures experienced for a significant period of time. Short-time extremes are ignored. These design temperatures are followed in the design of heating equipment and insulation.

DEGREE DAYS are shown on the right-hand map below by the solid red lines. Degree Days, used to express severity of a normal heating season, is a term found by recording the number of days when the average daily temperature falls below 65° F. and the number of degrees this average is below 65° F. The product of these two is called Degree Days. For example, if a day in December has an average temperature of 35° F. it represents 30 Degree Days (65 – 35 = 30). A city experiencing 8000 Degrees Days per year has a tougher heating problem than one with only 3000 Degree Days.

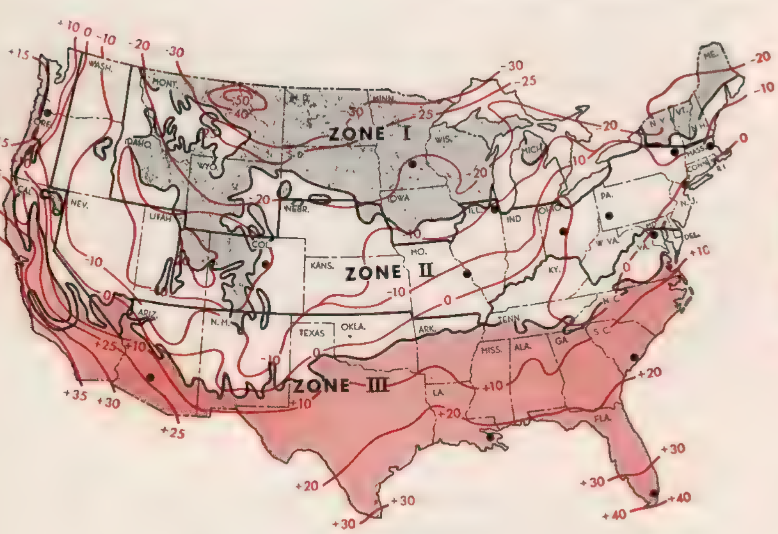
* * * *

Primitive Americans survived our climate in the bark "wigwams" and "long houses" of the Penobscots and Iroquois, the "tipis" of the Crows or the adobe pueblos of the Southwestern Indians.

Today something more is needed to stand between the indoor climate we seek and the outdoor climate served up to us daily. Something more than a good rain-shed, or a shield against wind.

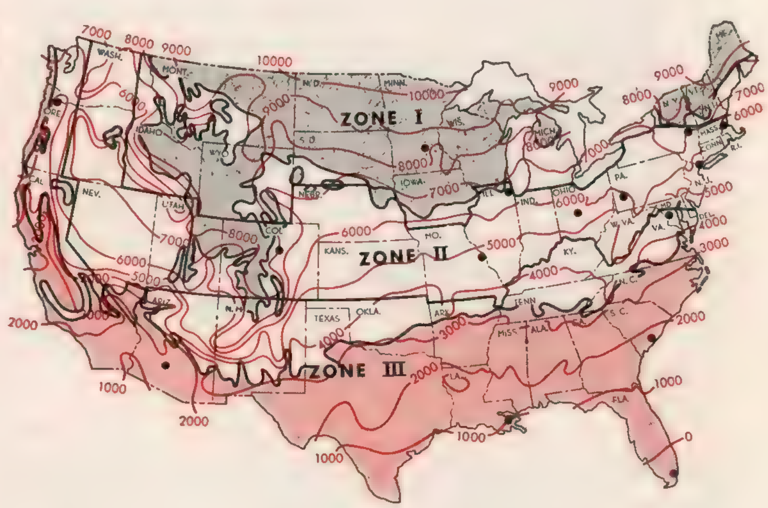
That something is insulation. Dr. Siple calls building insulation the great "arbiter" between indoor and outdoor climates; a cushion with a job to do in all climates.

WINTER CLIMATE ZONES AND TEMPERATURES



OUTDOOR DESIGN TEMPERATURES

Isotherms from Heating, Ventilating, Air Conditioning Guide, 1951, Chapter II.



DEGREE DAYS

Isotherms from "Heating & Ventilating" Magazine, Clifford Strock, Editor.

Heat Control

Heat Control: *Human comfort depends on controlled cooling*

You are comfortable only when you are not conscious of discomfort.

The moment you feel too cool or too hot, or feel a draft or begin to perspire, you are conscious of discomfort and therefore lack complete comfort. There are a lot of other causes of discomfort, like a hard chair, or an annoying fly or mosquito, or unpleasant odors or noises, but we will stick to the discomforts relating to temperature and humidity and air motion.

The problem of comfort begins within our bodies. Our food (and some of our drink) is the fuel for our own internal heating system.

We generate more heat than we can use. Some of it must escape. If it did not, our blood temperature would rise above its normal 98.6° F. and we would burn with fever. If we lose too much, we feel chilly. Protracted periods at either extreme result in death. Fortunately, Nature endowed us with a remarkably effective thermostatic control system and several ways of losing heat.

The rate at which we lose heat is a direct measure of our body comfort (with respect to temperature, of course). Therefore in winter we provide enough heat and clothing so we will not cool too rapidly. In summer we reduce clothing to the extent social proprieties will permit, and then provide shade, breezes, air cooling and air drying to help us get rid of enough surplus heat at the right rate.

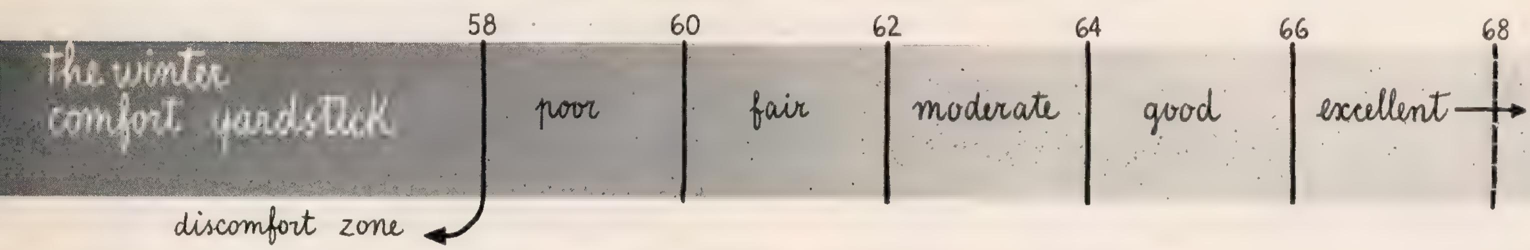
We can lose this excess heat from our bodies by five methods, or gain heat from our environment by three of them. Heat loss may be by *conduction* or touching cooler things; by air that is cooler than our skin moving over our bodies or clothing, called *convection;* by being near cooler surfaces, as when near a cold wall or window, known as *radiation;* by *evaporation* of perspiration from the skin, greatly aided by breezes; and by the heat carried from our lungs as we breathe, *respiration.*

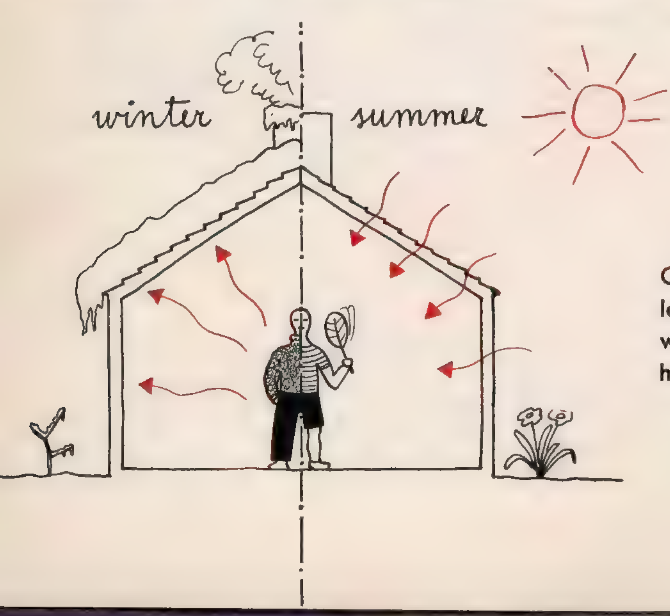
These five methods are further defined in the column at the extreme right.

Although the most obvious way of keeping comfortable is by keeping the air temperature around 70° F. to 75° F. for persons at rest, or somewhat lower for persons actively at physical work, comfort depends even more on other means. For example, cool air moving a bit too fast becomes an uncomfortable draft; or air that is too moist retards normal evaporation and feels muggy or close in summer, clammy and extra chilly in winter.

Of all these methods radiation is most important in the control of body temperature and comfort indoors, except possibly for drafts. Therefore in winter we want the surfaces that surround us to be warm, in summer, cool.

Observation has fairly well established a yardstick of winter comfort based on the temperature of the inner faces of the walls, floor and ceiling that encloses the room where we are. If these surfaces are close to the desired air temperature (ranging from 70° to 75° according to age, activity, and personal "taste")





Cold walls in winter (extreme left) make us feel chilly; warm walls in summer add heat and discomfort.

the conditions are generally accepted as excellent. If they are as much as ten degrees cooler, they are at the fringe of perceptible discomfort.

In summer, we can tolerate a 75° air temperature indoors with entire comfort; sometimes dry air at 80° does not seem too hot. But if the walls, ceiling and floor are warmer than these limits, by even a few degrees, we feel over-hot and want to get outdoors or wherever it *seems* cooler. Actually we want to get away from proximity to these warmer surfaces because they do not absorb enough heat from our bodies by radiation. The summer comfort yardstick is not established as precisely as the winter scale because so much depends upon relative humidity and air motion in addition to temperature.

Very practical considerations are related to these facts.

If we are uncomfortable when near surfaces that are too warm or too cool, we subconsciously avoid them. Hence a room with walls that are not at the right temperature shrinks in useful size. Dr. Siple says we lose about three feet of useful floor space when surface temperatures are above or below the comfort zone in our yardsticks.

But more than personal comfort is involved. Research indicates that when overheated we tend to make mistakes, become indolent, prone to accidents. Overcooling makes us physically active for a time, but soon uses up too much energy that could be devoted to productive purposes. In business and industry a comfortable temperature environment pays dividends.

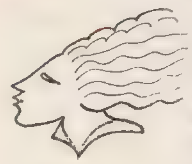
Building insulation, as we shall develop later, is such an economical and practical medium for achieving these ends, that it has become an indispensable element in modern buildings in nearly all climates.

HOW WE LOSE (OR GAIN) UNWANTED HEAT

1. BY TOUCH, OR CONDUCTION.

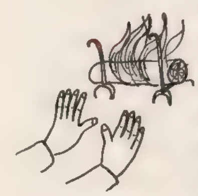
Heat creeps from your body when you stand on a cold floor or touch anything cooler than your skin. You are warmed when you touch something warmer than you are. Heat creeps through building materials the same way—put one end of an iron poker in a fire and the handle soon gets too hot to hold.

2. BY DRAFTS, BREEZES, OR CONVECTION.



Heat moves from solid materials to air and from air to solid materials by convection. It is a "washing" action, with heat always going from the warmer substance to the cooler. Drafts in winter feel chilly; gentle breezes in summer are welcome cooling aids. Outdoor air gets all its heat by convection as it washes over the ground, the leaves of trees or the surfaces of buildings in the sun.

3. BY RADIATION.



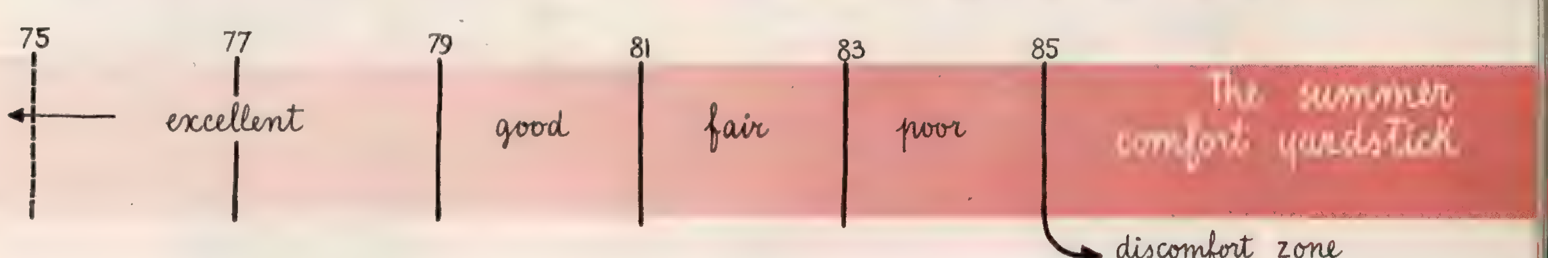
Heat can jump across air spaces without heating the intervening air. This is how the sun heats the earth, or an open fire toasts your hands. Like light, heat moving by radiation warms whatever it "sees" in any direction. It can be shaded; that is, the surface receiving the heat blocks it from warming what is beyond. Steam and hot water radiators and radiant panel systems all use this radiation principle in part.

4. BY EVAPORATION OF PERSPIRATION.

When water evaporates (or changes to vapor) it absorbs heat from adjacent surfaces or air. Thus gentle breezes, carrying off perspiration, cool your skin. Wet roofs are also used for cooling.

5. BY RESPIRATION, BREATHING OR "VENTILATION".

Whenever you breathe, cool air enters your lungs, comes out warmer, carrying some of that excess body heat with it. In buildings the nearest simile is ventilation; when you open a door or window in cool weather, some of the warm air escapes.

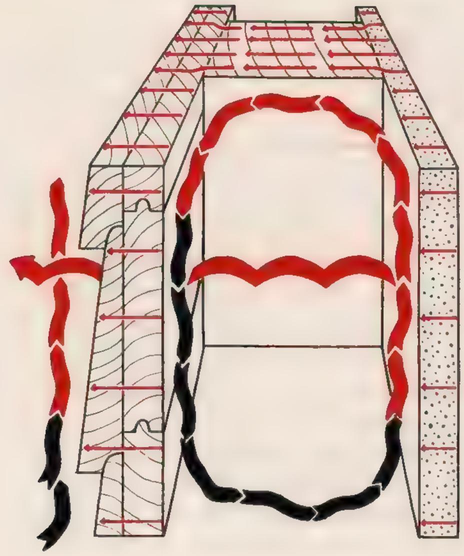


When a hungry man says "Let's stoke up" he is speaking more accurately than he may know. For the food we eat is fuel for our internal heating system, that constantly generates more heat than we can use.

We lose valuable room space if wall surfaces are too cool (or too hot). Since our bodies are constantly closer to floors than to walls, and usually closer to walls than to ceilings, it is most important to keep floor and wall temperatures in the comfort zone.

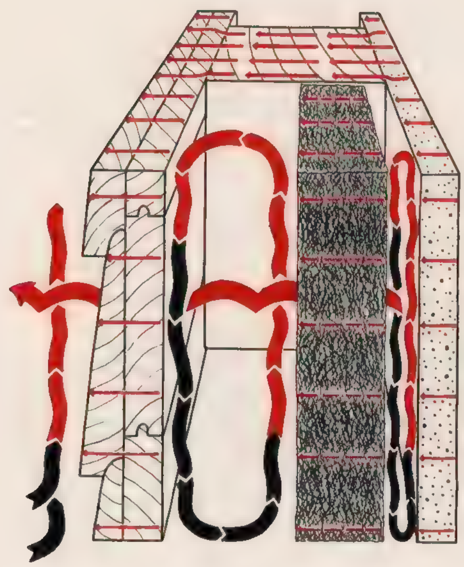
HEAT USES THREE METHODS TO PASS THROUGH BUILDING SECTIONS:
RADIATION, CONDUCTION AND CONVECTION

no insulation



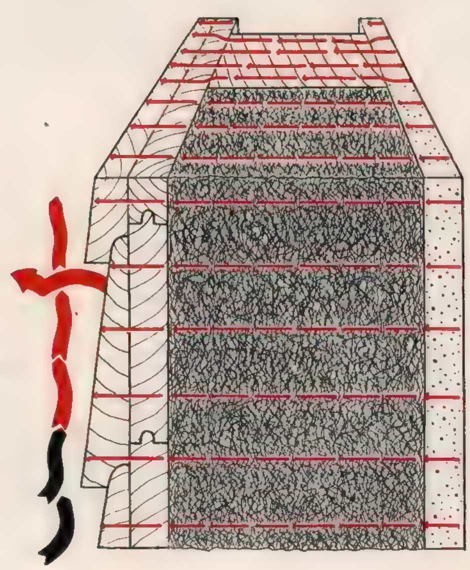
Key to heat movement
by radiation (jumps)
by conduction (creeps)
by convection (washes)

blanket insulation



RESULTS COUNT
No matter where the heat comes from, or how it travels, the only important fact is how much heat gets in or out of the building, by all methods combined.

fill insulation



Heat Control: *How heat moves through building materials*

Because human bodies are tolerant within a narrow range of climatic conditions there is an excess of heat in summer and a deficiency in winter which our buildings must rectify. We must set up barriers to heat in the shells of our buildings. These barriers must retain the heat we generate within buildings in winter—at constantly increasing cost—and keep out the excessive heat the sun delivers in summer.

To understand how these barriers do this job we must first understand how heat moves. We could skip this study were it not for the fact that there are many misconceptions that confuse a host of people.

Just for the fun of it, mentally answer these questions before you read further: What is cold? Does cold penetrate things, like buildings? In what direction does heat travel? Does it always rise? Is radiant heat a special form of heat? When you use radiant heating systems is it best to use reflective insulating materials? What is the force that makes heat move? And how important is this force in building design?

Heat, like electricity, is a form of energy. And like electricity, it is easier to accept than to explain.

Cold is the absence of heat. Just as a vacuum is the absence of any gas. There is no such thing as cold in the technical sense. Cold *seems* to penetrate clothing, and buildings, but what we actually feel is heat escaping too rapidly for comfort.

Heat always moves from something hot or warm to something else that is cooler. It's like air wanting to fill a vacuum, or like light always seeking to penetrate and banish darkness.

Heat travels in the first three ways described in the panel on page 17, and illustrated at the left. These three ways are conduction, convection and radiation. (Buildings also can lose or gain heat by evaporation or condensation of moisture, and by ventilation, but these methods will be treated later.)

Whatever means of travel it may use, it is still the same energy. Radiant heat, for example, isn't any special kind of heat with special properties. Hence radiant heating systems do not need any special kind of insulation to make them effective.

To the designer, builder or owner of a building only one fact is important: *How much heat gets through by all methods combined?*

This, in turn, does not depend on how the heat is generated or distributed indoors, but rather on how much heat is present indoors compared to how little heat is present outdoors or vice versa. It is this differential between indoor and outdoor air that tells how much "pressure" there is to induce the heat on one side to try to get through to the other side.

This pressure is largely due to climate. It is the most important factor in all heating and cooling calculations. A ten percent error in any other item, such as the heat resistance of the building materials and insulation, becomes a smaller error in the final result. But a 10% error in estimating the difference between indoor and outdoor temperatures remains a 10% error in the final performance of the system.

That is why knowledge of your local climate is so important.

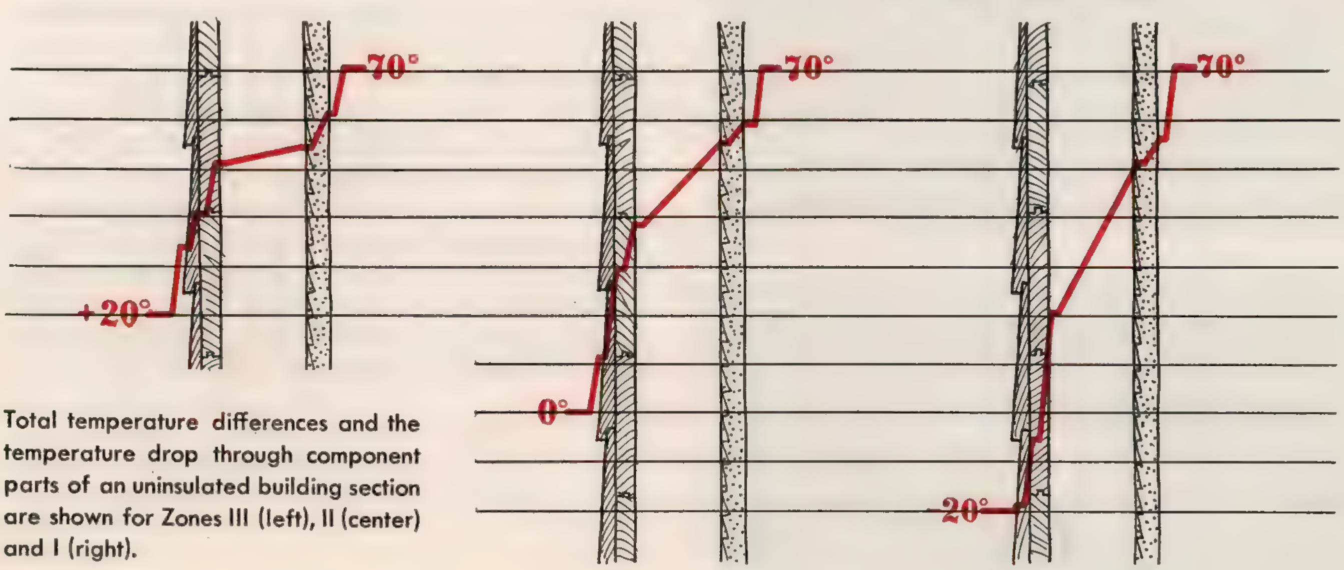
* * * *

You cannot stop heat movement.

The best you can do is to slow it up. But you can do that very effectively.

There are three ways to do it. One uses trapped air, the second uses heat-reflective materials and the third uses colors that absorb less heat.

THE "PRESSURE" THAT GOVERNS HEAT MOVEMENT IS THE TEMPERATURE DIFFERENCE



Total temperature differences and the temperature drop through component parts of an uninsulated building section are shown for Zones III (left), II (center) and I (right).

This smart bird is keeping warm by fluffing out its feathers—instinctively using the principle of insulating with entrapped air.

Heat Control: *How trapped air traps heat*

Still air is the best heat insulator we know. But air is seldom still. The slightest change in temperature will make air expand or contract; the warmer air becomes lighter and floats above the cooler, heavier air. So the job is to keep air still.

We can do it with many materials. One method is to enclose small particles of air within closed cells, as in cork or cellular glass, or foamed plastics. Another is to trap it in deep caves and passageways between particles, as in granular materials like pumice or vermiculite.

A third is to employ the principle that thin films of air cling persistently to all surfaces and thus to use masses of fine fibers which provide a tremendous surface area to which the air clings. Fur, wool, feathers, and mineral wool insulations are examples.

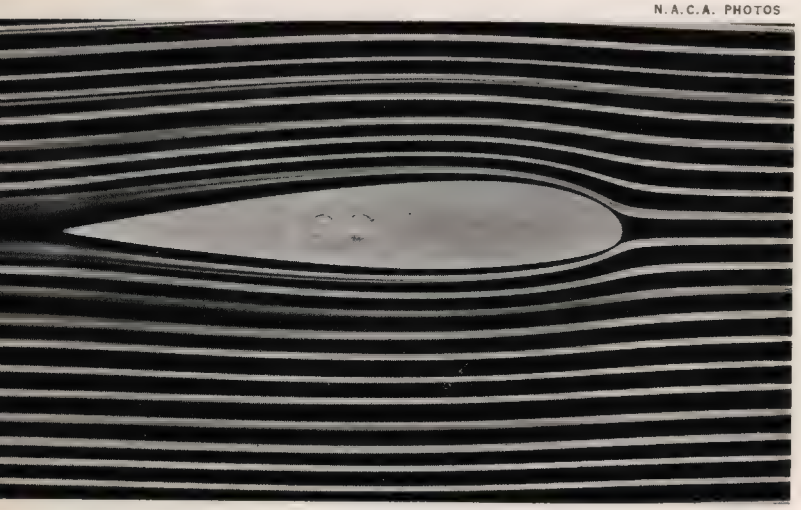
Aircraft designers are plagued with this film of air. It adds to the "drag" of aircraft in flight; it is part of the problem of breaking through the sonic barrier. It is clearly revealed in air tunnel tests of aerodynamic sections.

This film of air is so definitely a heat barrier that it must be considered in all heat transmission calculations. (See page 104.) It varies with wind velocity, but within the insulation we do not usually have any "wind" to contend with.

Nature uses the same principle many times. Light, fluffy snow is an excellent insulator for the ground, as every farmer knows. Packed snow and ice are not good insulators—the air has been squeezed out. Birds fluff their feathers, animals fluff up their fur in cold weather. Our human goose-pimples are said to be the last vestige of the fur our presumed ancestral apes wore; when we are chilled, these pimples once made our hairs stand nearly on end.

Smoke streams around an airfoil section reveal the thin film of air that clings to all surfaces and helps retard heat loss or gain. Lower test shows that when high velocity air hits a surface directly it thins down this protective film, hence increases heat transfer.

N.A.C.A. PHOTOS



WHY DIFFERENT MATERIALS TRANSMIT HEAT AT DIFFERENT RATES

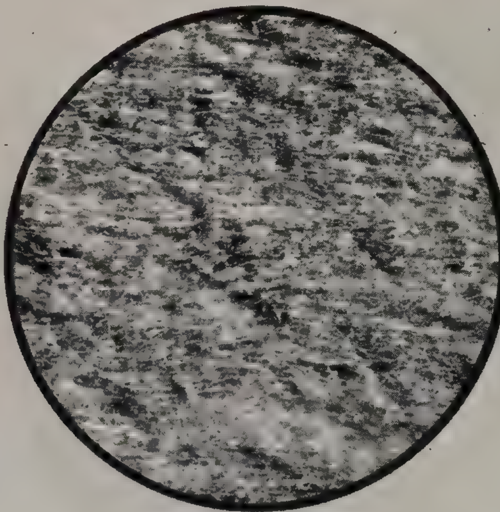
The reasons some insulations using the trapped air principle conduct more or less heat than others include these things:

1. *The ability of the material forming the fibers or cells to conduct heat along their length.* Solid glass may have a conductivity ranging from 4.7 to over 9 heat units (Btu), some plastics conduct only 1 or 2 heat units, some minerals over 15 heat units, when measured under identical conditions. The thickness of the fibers or cell walls also affects heat transfer by this method.
2. *The ability of adjacent fibers or cellular particles to transmit heat by conduction,* from particle to particle or fiber to fiber. Hard cylindrical fibers or hard round granules have infinitely small points of contact through which only a little heat can move. Soft fibers or flat surfaced materials have larger contact surfaces that let more heat move.
3. *The orientation of these paths of heat flow,* either through the material in the direction of heat pressure, or across this flow. In the first case the path of heat conduction is short; in the second it may be quite long.
4. *The size of the particles of trapped air* or the closeness of adjacent films of air on the fibers or granules. If the particles of air within a cell are too large, they can set up minute convection currents. If the fibers or granules are too coarse, the air films adhering to their surfaces do not touch each other, leaving gaps through which free air can establish convection currents.

These methods are graphically illustrated by the line drawings on the next page.

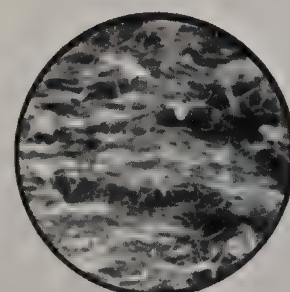
There is little or no movement of heat by radiation across these minute air cells or spaces; at least for all practical purposes it can be disregarded.

These reasons are quite sufficient to explain why one insulating material, one inch thick, may only transmit 0.22 heat units per square foot, when another may transmit 0.48 heat units, or over twice as much, under otherwise identical conditions.

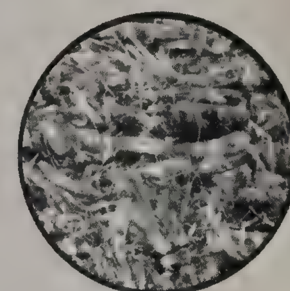


MINERAL (GLASS) WOOL

These photomicrographs are made at various magnifications to bring out the fibrous or cellular structure that entraps air and gives them insulating value.

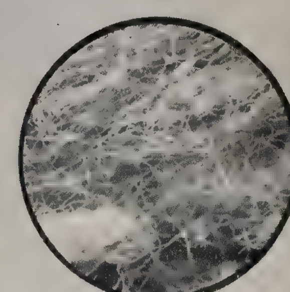


CELLULOSE FIBERS

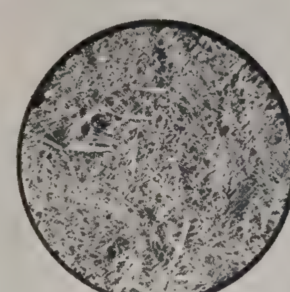


VEGETABLE FIBERS

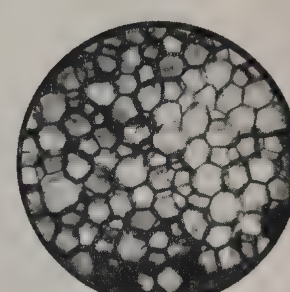
VERMICULITE



COTTON

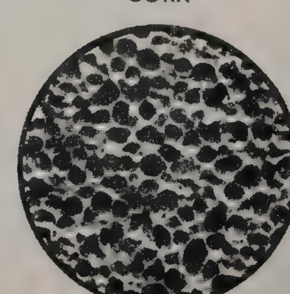


WOOD FIBER



CORK

CALCIUM SILICATE

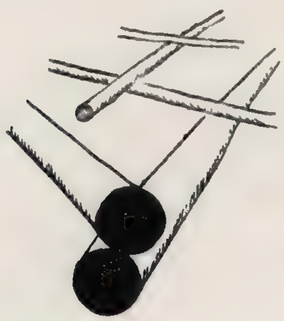


FOAMED GLASS

PITTSBURGH CORNING CORP.

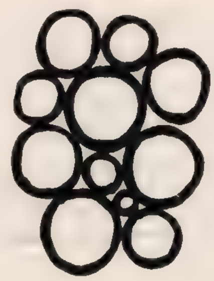
WHY DIFFERENT MATERIALS TRANSMIT HEAT AT DIFFERENT RATES

THE CONTACT OF INDIVIDUAL FIBERS, or cell walls, with each other affects the rate of heat flow by conduction through the solid elements.



Hard, cylindrical fibers, like glass, have infinitely small points of contact, transmit little heat from fiber to fiber.

Soft fibers flatten at their contacts, thus allowing heat to move from one to another more readily.



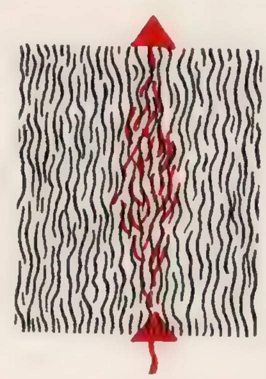
Hard granules have few and small contact points unless graded sizes fill all the interstices.

Honeycomb materials have solid, interconnecting walls that can conduct heat around the entrapped air.

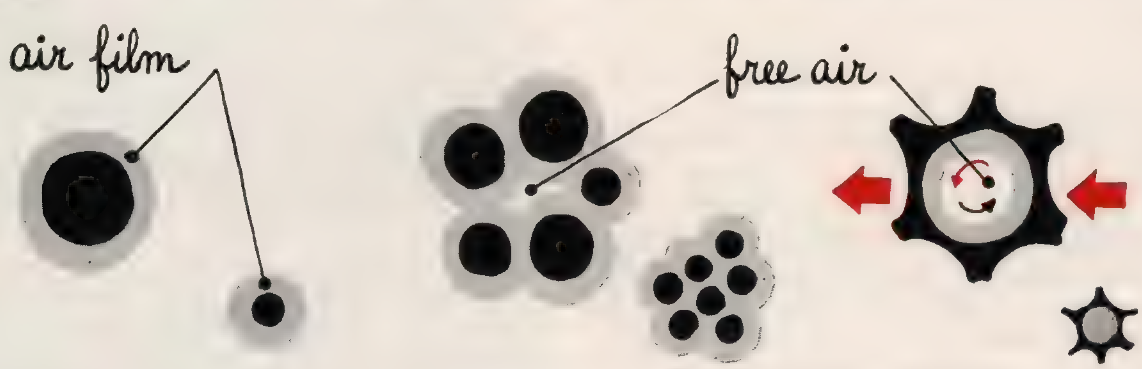
THE DIRECTION OF THE PATHS OF HEAT FLOW by conduction through the solid materials affects the rate of heat movement.

Left: When the fibers or solid elements of an insulation lie across the path of heat flow, the distance heat must travel by conduction is long. Only one quarter of a heat unit passes through this example.

Right: If the same fibers were oriented parallel to the direction of heat flow, the path of conducted heat is shorter and nearly a third of a heat unit will be transmitted under equal conditions.

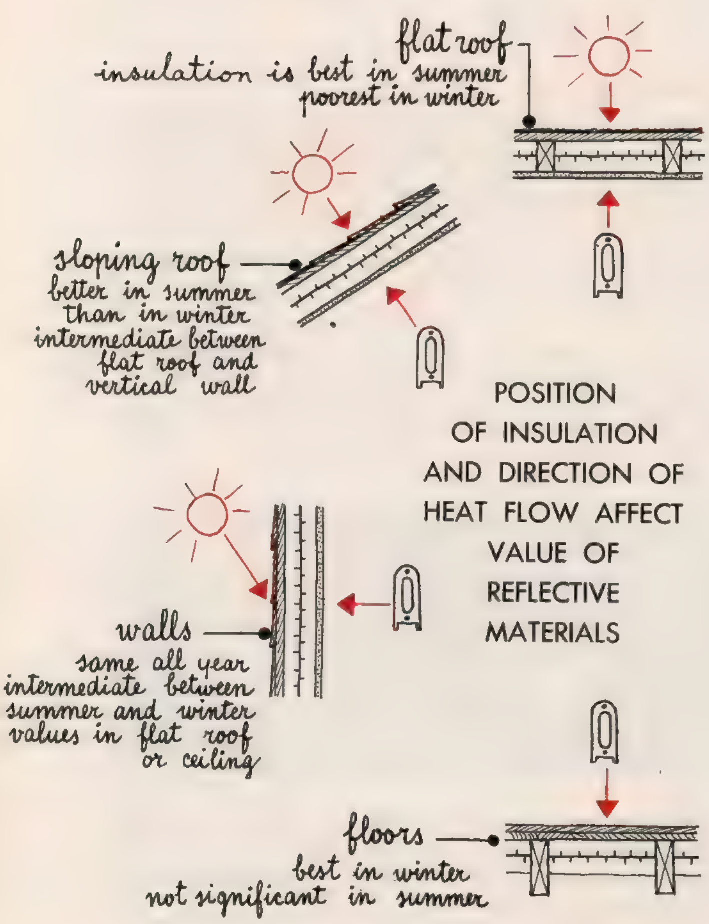


THE SIZE OF THE AIR PARTICLES or the closeness of the air films affects the movement of heat by convection.



The thickness of the film that clings to surfaces is approximately constant in still air; hence, in a given space, if fibers are small, they provide more surface and hold more air then large fibers which may leave paths for air to move freely by convection. Even within cells there is an air film. If the cell is large the free air within can set up minute convection currents, thus transmitting some heat across the cell. Small cells have no such convection movement.

A reflective material may be combined, as here, with a blanket insulation to improve winter value. Note how air space is provided by keeping reflective surface well above ceiling line. (Incidentally, the vapor barrier is not continuous over the edge of the ceiling joists.)



POSITION OF INSULATION AND DIRECTION OF HEAT FLOW AFFECT VALUE OF REFLECTIVE MATERIALS

Heat Control: *How heat can be reflected*

Checking the flow of heat by "reflective" materials is the least understood and most frequently mis-used of the three insulating methods.

Let's clear away any confusions.

Gold, silver, chromium, aluminum, lead, copper, zinc and iron (in approximately that order) when free of oxides or other surface films, have the property of reflecting much of the heat which radiates through the air to their surface, as a mirror reflects most of the light it receives. For cost reasons aluminum is the material most commonly used as a reflective heat insulation, though other materials could be used.

Each of these metals *conducts* heat very rapidly; aluminum over 1400 times faster than wood, steel over 300 times faster than wood.

The ability to reflect heat varies with the temperature of the heat source to this extent: heat from high temperature, "incandescent" sources like the sun, behaves more like light and brings in the question of "absorptivity" of the color of the material (see page 25); while "black" heat from low temperature sources, like radiators or the human body, is reflected quite effectively without respect to color.

This reflective capacity has its counterpart, the ability to emit heat slowly from the surface away from the heat source. The two together represent 100%; that is, if the "reflectivity" of a material is 95% (meaning it turns back 95% of the heat received radiantly) then its "emissivity" is 5%. These figures apply to bright aluminum foils. Aluminum paints reflect about 75%, emit 25% depending on the vehicle covering the metal flakes; lead is about 50-50 each way.

Thus, if foil is mounted on some non-reflective material which first receives the heat, its low emissivity is just as effective as its high reflectivity to heat approaching its exposed face by radiation. This is illustrated on the next page.

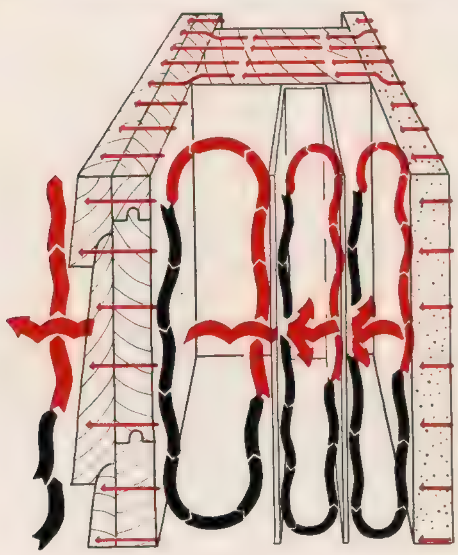
For reasons not easily explained, the effectiveness of reflective insulations in buildings varies with the direction of heat flow—up, down, sideways, diagonally. It also varies slightly with the temperatures on the cold and warm sides.

How much heat goes through a building section by radiation depends on its construction. Heat transfer through surfacing materials and framing members is by conduction alone. Across internal air space, heat travels by convection and radiation. The relative amount moving by these two methods depends upon the character of the material facing the air spaces. It is not important how much travels by each method so long as the correct total heat transfer is found.

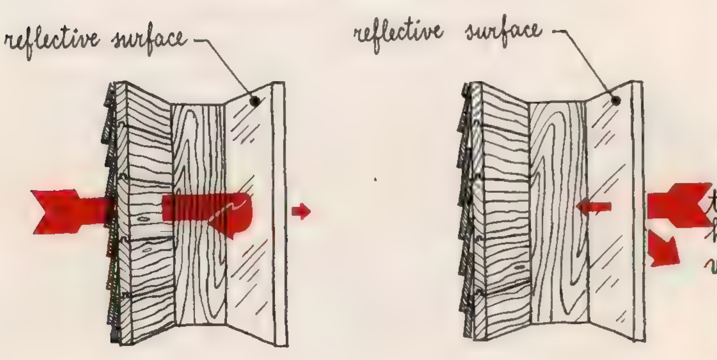
Finally, the sheet metals and foils, unless the latter are so thin as to have many pin-holes, are substantially perfect vapor barriers. The significance of this will be developed on page 40.

From these established principles and properties it is possible to list the practical "do's and don'ts" governing the use of reflective insulation materials as given at the right. For the story on "absorption" of heat in relation to color, see the next page.

HOW HEAT MOVES THROUGH BUILDING SECTIONS—USING REFLECTIVE MATERIALS



WHEN "REFLECTIVITY" WON'T WORK "EMISSIVITY" WILL . . .



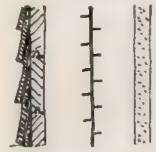
REFLECTIVITY   EMISSIVITY

Reflective materials work regardless of which side first receives the heat. The face opposite an enclosed air space either reflects most of the heat radiating toward it, or it emits slowly the heat coming the other way.

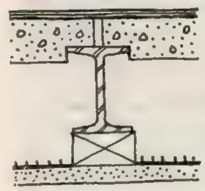
DO'S AND DONT'S ABOUT REFLECTIVE INSULATION

DO'S:

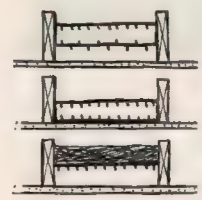
1. Always provide an *enclosed* air space opposite any reflective material. The effectiveness of the air space is greatest at depths of ¾" or more (up to the total depth of the wall, floor or ceiling.) Dividing an air space with a foil provides two working air spaces.



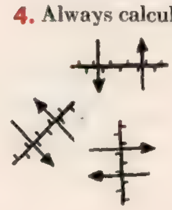
2. Always attach reflective foil materials to non-conductive supports, such as wood framing members or furring strips. If attached to cold steel or masonry supports, the high conduction of the reflective foils will carry heat "sideways" from one support to the next and thus disturb its calculated effectiveness.



3. Always use at least two reflective surfaces facing common (preferably separate) air spaces, if climate and occupancy conditions indicate condensation may occur, unless the foil serving as the first vapor barrier is close to the warm side of the construction or is kept above the indoor dew-point temperature by other insulating materials. (A single foil that is too cold will develop condensation on its inner faces, as explained later.)

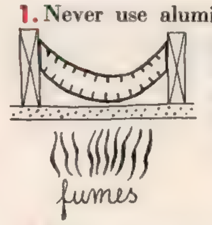


4. Always calculate the effectiveness of the reflective insulation for both *winter* and *summer conditions* (direction of heat flow) and for the *position* of the insulation (vertical, diagonal or horizontal), so that the amount used will meet local climate and other project conditions. (For calculation methods see page 105.)

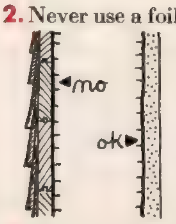


DONT'S:

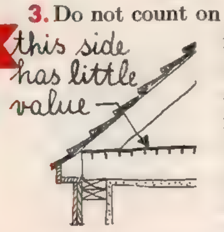
1. Never use aluminum foil in contact with wet plaster or cement where the alkaline reaction can rapidly destroy the metal. Also pre-test any reflective material in the presence of unusual fumes or gases to determine resistance to corrosion or serious oxidation.



2. Never use a foil or sheet metal reflective material on the cold side of the construction, *unless* an equally effective (or, if possible, a better) vapor barrier is provided close to the warm side. Any moisture reaching them when the surfaces are cold will surely condense to water or frost.



3. Do not count on much insulation value from reflective surfaces that face an open attic or a room. Leading authorities recognize some value against heat flow down, negligible value for heat flow up. The FHA method of calculation given on page 105 assumes that air currents and ventilation in such spaces reduce the effectiveness of exposed foils to that of their surface film resistance.



4. Never assume any insulating value whatever for reflective materials that are in contact on both faces with other conductive materials, such as foil-laminated papers used as sheathing papers, vapor barriers, or as components in built-up roofings.

UNITED AIR LINES

The white paint used to cover the tops of United Air Lines' Mainliner 300 (DC-6) planes acts as a "cabin cooler" while aircraft are waiting at ground terminals. Tests have proved, according to airline officials, the paint keeps passenger cabins as much as 15° cooler.

A. DEVANEY, INC., N. Y.

The same principle, long used in Bermuda and in our own southern areas, makes a white-roofed house more comfortable in hot sun. Since sun heat is just as severe in northern areas (see map, page 31) this trend is gaining popularity in all parts of the United States.

Heat Control:

How color affects heat absorption

"White" heat and "black" heat have different effects on materials due to their difference in wave lengths and this fact adds to the confusion about reflective materials. By white heat we mean heat radiating from high temperature sources, generally hot enough to give off visible light, and by black heat the heat coming from sources ordinarily encountered inside buildings.

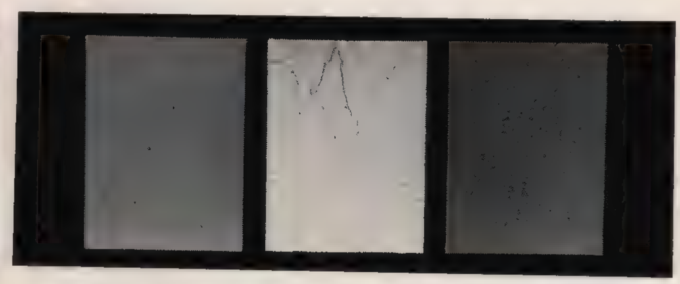
It is well known that light colors reflect light and dark colors absorb it. Within certain technical limits that do not need to complicate this discussion, heat waves from incandescent sources are similarly reflected or absorbed in approximate relation to color.

That is why United Air Lines has found it expedient to paint the tops of their cabins white. Although most people have come to believe that polished aluminum, such as the surface of a modern airliner, reflects heat, the aluminum has a grey color in sunlight, and like grey pigments, tends to absorb more sun heat than white.

That is why our canny New England ancestors, for generations, have painted their homes white, even at extra expense for maintenance, and their barns red. White, because it proved more comfortable in hot summers; red barns because red paint was the cheapest durable paint they could buy, and the animals couldn't complain.

And that is why a white roof will keep the attic or loft space cooler in summer than a grey or dark roof

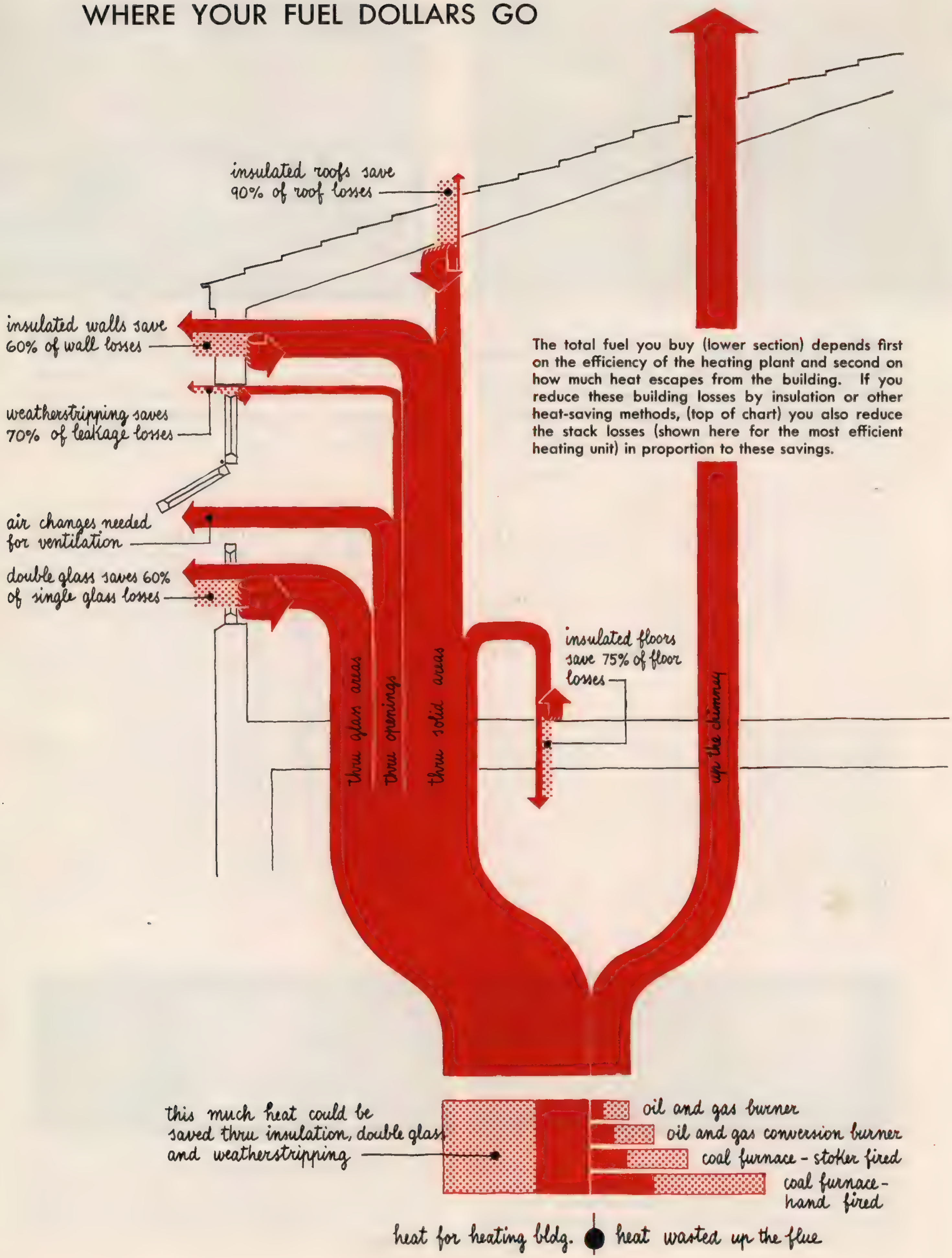
"White" heat, from ordinary incandescent lamps or the sun, shows that white (left panel) reflects heat, aluminum (center) becomes grey. Right panel is neutral grey for comparison. This demonstration explains the value of white-walled buildings, white roofs in hot sun.



CLE CLARK, DETROIT

"Black" heat is reflected best by the aluminum foil which appears whitest of the same three panels in these simulated laboratory tests using heat-sensitive photo film. This test is comparable to the low-temperature heat sources used within buildings.

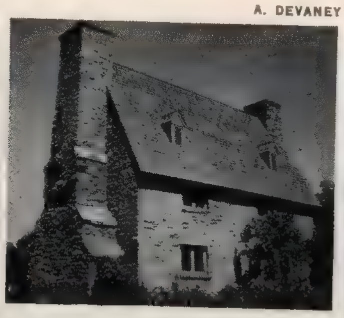
WHERE YOUR FUEL DOLLARS GO



The total fuel you buy (lower section) depends first on the efficiency of the heating plant and second on how much heat escapes from the building. If you reduce these building losses by insulation or other heat-saving methods, (top of chart) you also reduce the stack losses (shown here for the most efficient heating unit) in proportion to these savings.

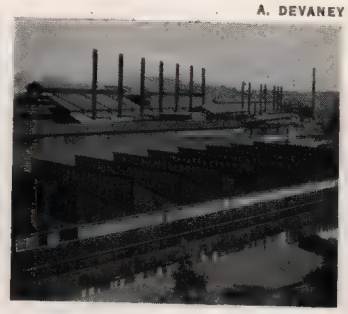
A. DEVANEY

A. DEVANEY

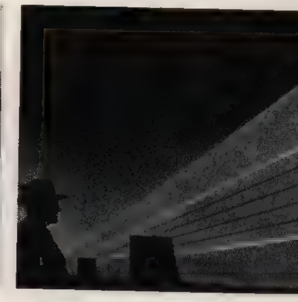


EWING GALLOWAY, N. Y.

A. DEVANEY



THE AUSTIN CO.



The large chart opposite cannot be applied to any specific building because each has a different ratio of glass to solid areas, different materials, different ventilation requirements. For example, three residences in three climate zones studied showed 79% of the heat was required for transmission losses, only 21% for ventilation. Three office buildings showed 23% transmission losses, 77% for ventilation. Three theaters had 17% transmission and 83% ventilation losses. Similarly compare the glass area of the UN Secretariat (left) with a windowless aircraft assembly plant pictured on the right.

Heat Control:

HEAT LOSSES . . .

the Winter problem

Between the inside and outside of our buildings we erect a conglomeration of materials designed to support loads, to look well, to shed rain and snow, to resist wind, and to keep heat out in summer and hold it inside in winter. Often within these structural shells there are air spaces as well as solid materials.

If the materials and air spaces alone were *efficient* in keeping heat in or out, as the need arose, there would be no insulation industry.

Although wood, when dry, is the best insulator that has sufficient structural strength to serve as a supporting material, even a wood-framed house costs too much to heat, is too chilly for comfort in winter, and often too hot in summer. We didn't realize that until we learned how much better a house could be if properly insulated.

All the heat we put into a building in winter, (and all the power we may need for comfort cooling in summer) eventually escapes. The fuel we buy contains heat—and its cost is going up steadily. We buy just enough heat in fuel to balance the escape of heat from the buildings. Here we are dealing with heat losses. See the diagram opposite.

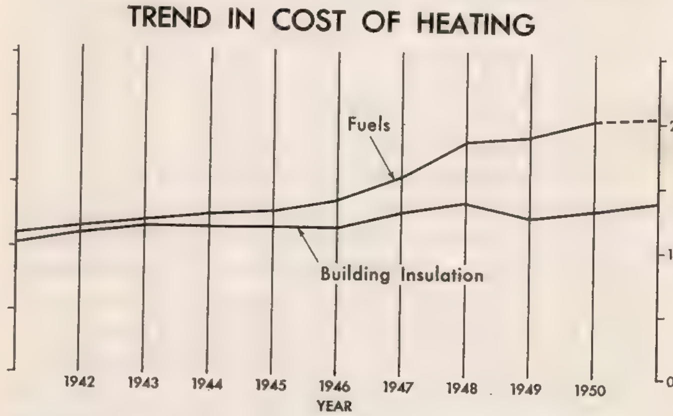
Some heat is lost up the chimney because our combustion systems are not perfect. How much of the total fuel is wasted here is governed by the efficiency of the heating plant. It pays to use the best.

Some heat is lost in the air that escapes through open doors or windows, or through the cracks around these openings, or with the stale air we deliberately push out to make room for fresh, clean air. Not much of this heat can be saved unless the losses through cracks are greater than we need to keep the air fresh. These crack losses can easily be reduced 60% to 80% with good weatherstripping, which also keeps out unwanted dust and some outside noise.

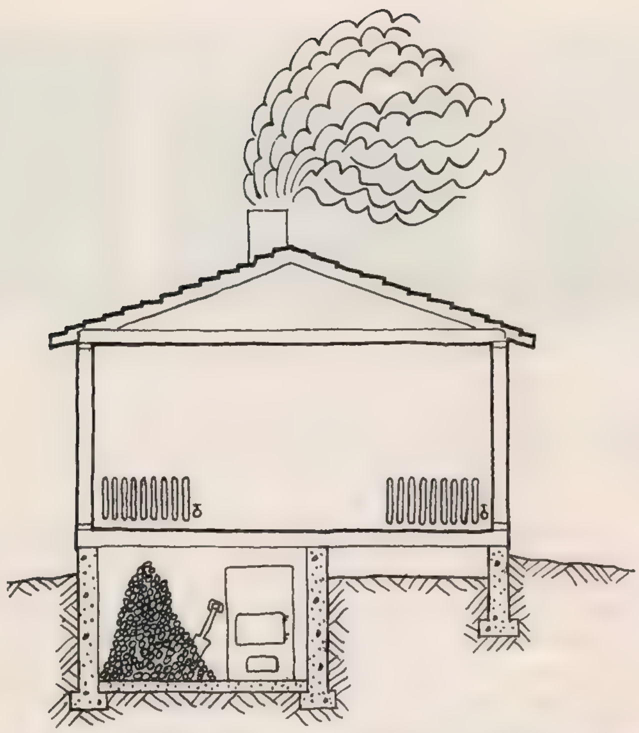
A considerable amount of heat is lost through glass because this thin material alone is not a good insulation. The modern trend toward large window areas increases heat losses and calls for a larger heating plant, but some heat comes back in with sunlight, so the balance is fair (in terms of fuel consumption) where the sun shines more than half the winter daylight hours. By using two panes of glass with entrapped air between, we can reduce these window losses nearly 60%, although even then the heat loss is much greater than through normal construction materials.

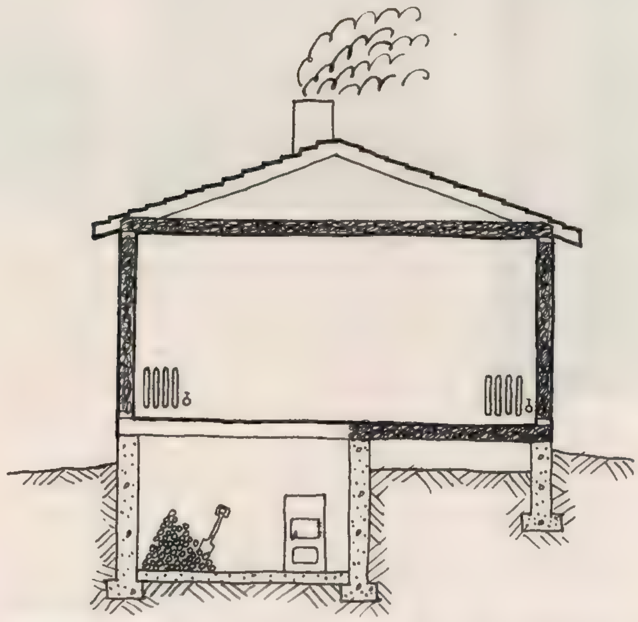
All the rest of the heat escapes through the opaque parts of the walls, the floor and the top-floor ceiling or roof. In most buildings these surfaces represent the largest areas. They can be insulated with the materials called building insulations. Savings in these areas can be very considerable indeed—they can range from 26% for a floor slab on the ground up to more than 90% for a plaster ceiling with the average running 75% to 80% if maximum insulation is used.

TREND IN COST OF HEATING



Fuel costs have risen so substantially during recent years that methods of reducing heat losses are now of paramount importance. Building insulation costs (one widely used material) have remained comparatively stable.





Insulation saves money two ways. By reducing heat losses it makes possible the installation of a smaller, less expensive furnace or boiler, smaller ducts, registers or pipes and radiators. By saving fuel every year the building is heated, it first repays its initial cost and then continues to save each heating season for the life of the building.

Don't try to add these savings. By themselves they add up to well over 100% and suggest you would have to cool your building in winter. But by *weighting* each percentage according to the area of each construction involved, you get the values contributed by each means of conserving costly heat.

For that reason no flat claims can be made for any material. Each building has a different amount of roof area, wall area, glass area, crackage around openings, ventilation rate and type of construction. Even furnaces, boilers and fuels differ. Every building must be figured by itself.

ECONOMICS OF INSULATION The cost of building insulation materials, in relation to the cost of fuel their use can save, is so low that an investment in insulation normally pays very substantial "dividends".

This is particularly true in Zones I and II; the return in Zone III is still substantial compared to ordinary "safe" investments, but the rate of repayment is moderate and the chief benefit comes from the element of comfort, which we will develop later.

You would undoubtedly consider an annual return of 10%, 20%, 30% or more on an investment in stocks or bonds exceedingly favorable, especially if no risk were involved. Yet such rates of return are paid by insulation if you will accept a saving in fuel cost as equal to a cash dividend.

These savings can be roughly appraised from the "Economy Rating" given for typical building sections in Part II (pgs. 62-116) by comparing the dollars saved annually with the estimated cost of installing the indicated insulation in 1,000 square feet of area. For example, if you estimate the insulation will cost, installed, about 15 cents per square foot, or $150 per 1,000 square feet, and the "Economy Rating" shows an annual savings of $30, then it would take only five years to save the initial cost, which means you would realize a gross return of 20%.

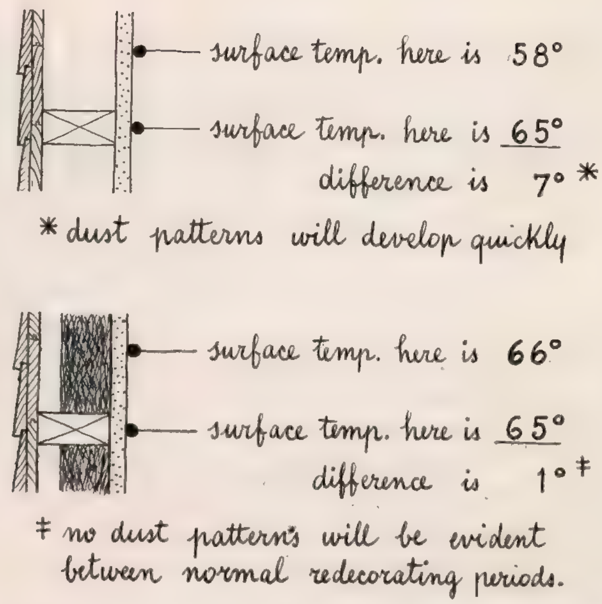
Actually, certain corrections would be needed to arrive at precise figures. You would adjust your local fuel costs and the efficiency of the proposed heating plant to the basis of 10 cents per "therm" used in these tables. (A "therm" represents 100,000 Btu—or heat units—and in this application means the heat units actually delivered to the building, not the gross heat available in the fuel.)

Another would be the normal depreciation allowance; a third the rate of return otherwise anticipated on the money invested in insulation.

Actually such precision methods are seldom necessary. A direct comparison is generally enough. And you must keep in mind that after the initial investment has been saved by lower fuel bills, that same saving continues every heating season thereafter.

Another, more direct saving, is in the initial cost of the heating plant. If the total heat losses from the building are reduced by the use of building insulation (or by double glass or windows, or weatherstripping and caulking around the openings), then the size of the heating plant, all heat distribution pipes or ducts and even the size of radiators, convectors or registers, can be reduced. This reduction in size is not directly proportional to the drop in total

Cold surfaces collect dust faster than warmer surfaces, even when no apparent moisture is present. Redecorating to clean or hide these dust patterns is required oftener if the building design is thermally unbalanced.



Surface temperatures vary when structural supports carry more or less heat than goes through spaces between. Using the right amount of insulation restores balance and stops development of dust patterns.

heat requirements because heating units are made in stepped ranges of capacity, and the cost of one size above or below the next is not proportioned to these capacity changes. However, these initial savings are real, and should be credited to the cost of the insulation that makes them possible.

GHOST MARKS Dust gathers on cold surfaces more readily than on warm surfaces. This fact has been proved by many experiments and observations. It is not due to the presence of condensed moisture on cold surfaces but seems to be due mostly to temperature differences and convection currents.

Experiments conducted by Pierce Foundation with highly sensitive apparatus prove that the rate of dust accumulation varies with any measurable change in temperature. But when these temperature variations are slight, it takes a long time for the dust patterns to become apparent.

This is the explanation for "ghost marks" sometimes observed in buildings that are not redecorated at frequent intervals. In houses the ghost marks reveal the location of studs, joists, or even individual wood plaster laths under the plastered surface. In masonry buildings the location of furring strips will show up, or areas where plastering is applied directly to the masonry will get soiled before furred or insulated areas will show any soil.

In all of these cases the soiled areas will be found to be cooler than the cleaner area. In outside walls or top-floor ceilings, the wood members are better insulators than the adjacent spaces (without insulation) and thus collect less dust because they remain warmer. A cold water pipe or drain line in a partition may reveal its presence by dark streaking, while a hot pipe or warm air duct in the same partition may ultimately show as a cleaner and lighter area. The reverse of this pattern is sometimes observed on the outside of light-painted dwellings in dusty areas.

If the temperature differences are slight, it may take four or five years or more for any visible evidence of ghost markings to appear. When walls and ceilings are cleaned or repainted within this period, the problem is not troublesome.

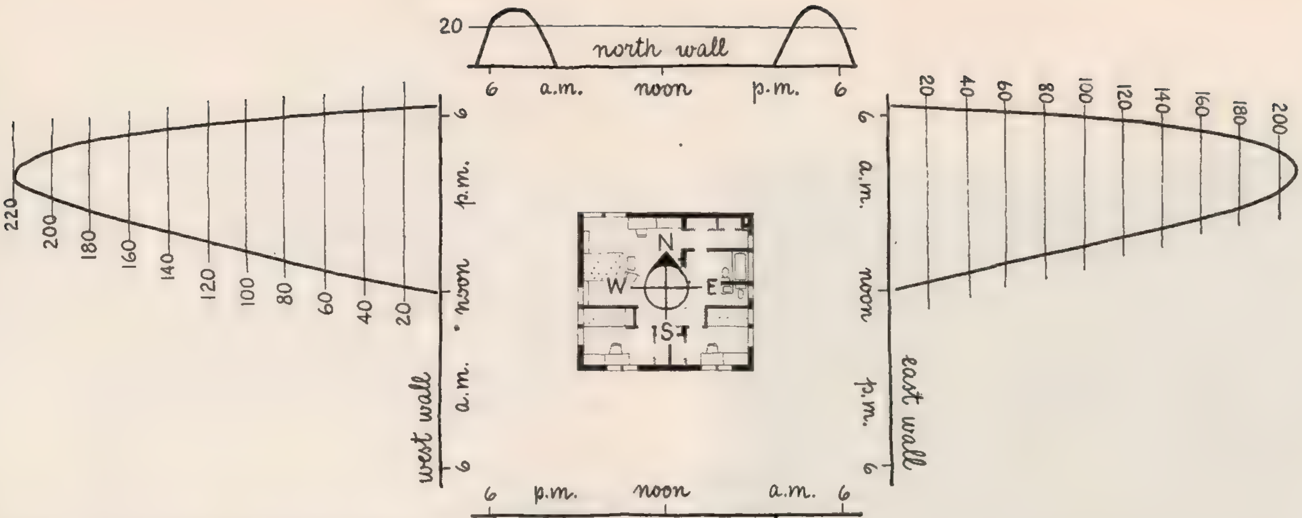
However, wide temperature differences cause dust patterns to develop in a single heating season.

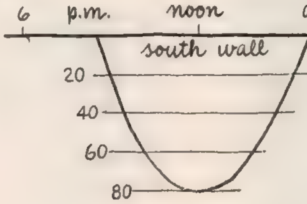
It is also obvious that surface temperatures near that of the air in the room will accumulate less dust than colder surfaces.

The use of building insulation keeps room surfaces warmer than they would be without insulation, and thus may reduce cleaning and redecorating costs.

According to the Minimum Property Requirements of FHA, a temperature difference of 6.5° F. or more presents a serious problem. From the author's observations over a period of fifteen years, a difference of only 3° to 5° may show noticeable dust patterns and thus accelerate cleaning or redecoration.

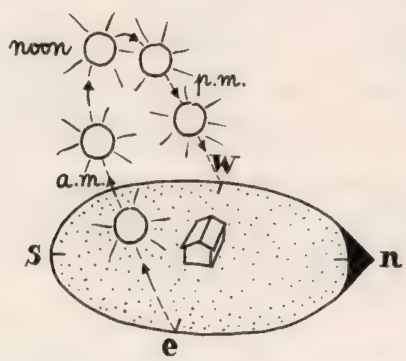
In the design of insulated buildings it is therefore important to "balance" the design by calculating the surface temperatures at structural support points as well as at insulated areas, and to bring them into close relationship by using insulation of the correct thickness or effectiveness.



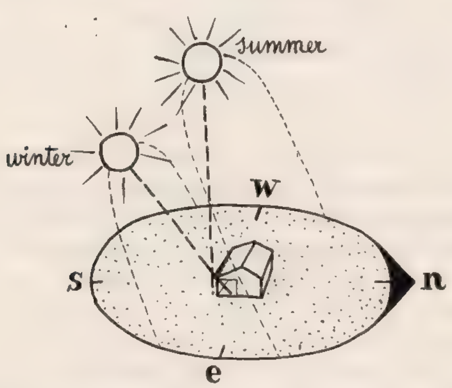


Below are the three factors governing the angle at which sun heat strikes the walls, affecting its impact.

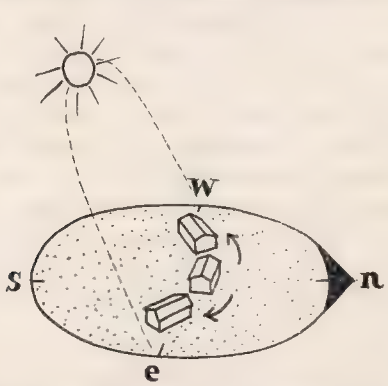
The curves and figures, arranged clockwise around the building, show how much heat, in Btu's per hour per square foot, reaches the vertical walls of a building in 35° latitude on July 21. Note that east and west walls get the greatest sun and sky heat load. The roof usually receives a still greater load and for more hours. Chart based on data by John Everetts, Jr.



Hour of day, from sunrise to sunset, changes the azimuth (horizontal angle) and altitude of the sun.



Season of year governs where the sun rises and sets and how high it gets at noon. Only in the summer does the sun strike north walls in the northern hemisphere.



Orientation of the building with respect to true north changes the angle of incidence of the sun. Similarly, the slope of a roof changes the impact on its surface.

Heat Control:

HEAT GAIN . . .

the Summer problem

Floridians have long claimed that their popular winter resorts are also delightful for summer vacations because their summer heat is not excessive. (They do not mind the humidity.) The same might be claimed by their competing resorts in the extreme southwest, as these two maps reveal.

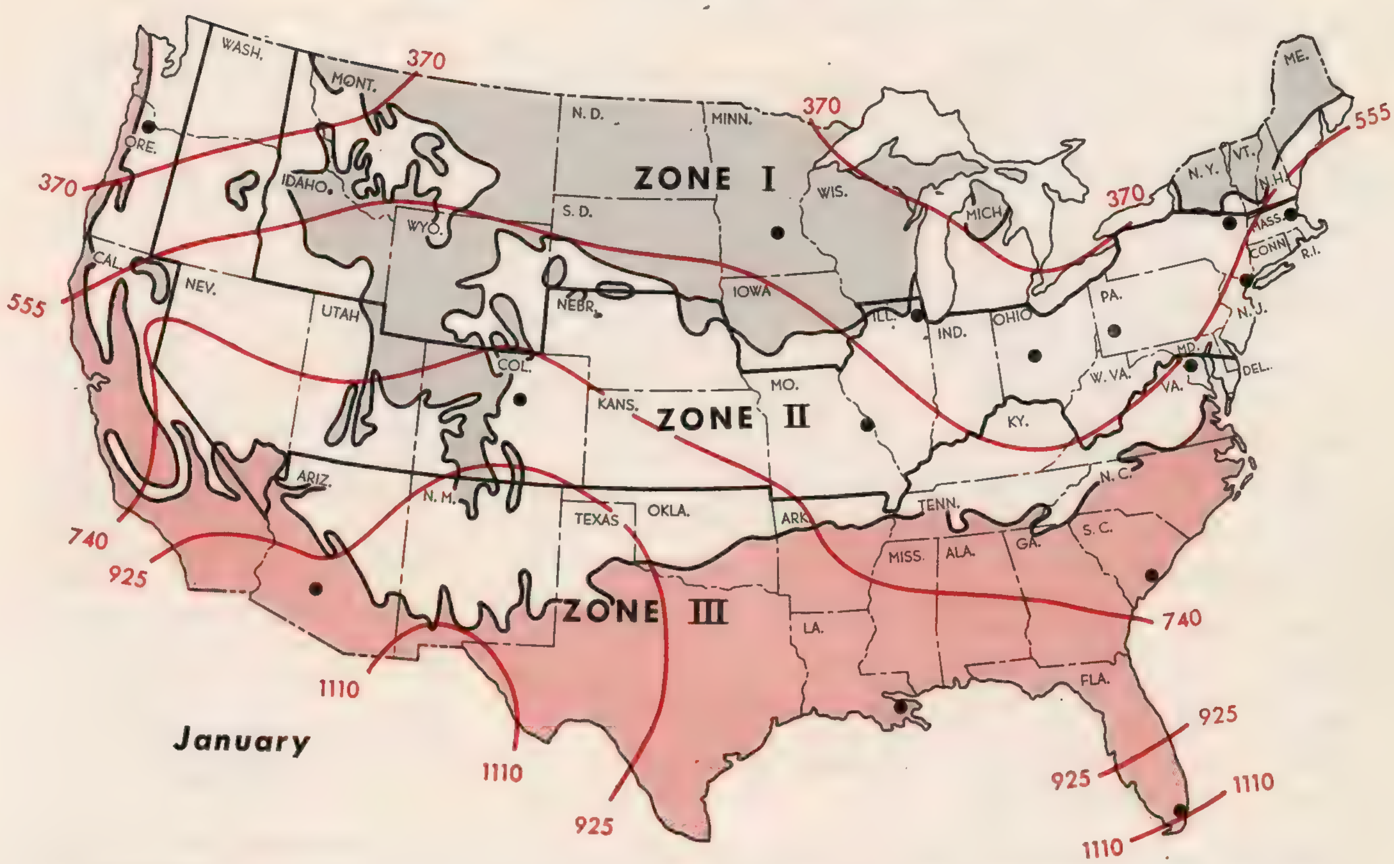
The maps on the opposite page show by curving red lines the sun heat (as Btu's per sq. ft.) received per day on a flat surface in January (upper map) and July (lower). In January the North receives less sun than the South, largely due to cloudy days and only partly due to latitude.

The lower map, for July, shows values on the northern border just as high as those on the Gulf Coast. On the tip of Florida and around El Paso, Texas, the maps show that 1110 sun heat units are received in winter, and only 1850 to 2220 in the summer. Across the northern boundary states, from Maine to Oregon, the winter map shows 370 units and the summer map 1850 to 2220 units. This demonstrates that summer sun heat is only *twice* as great as winter sun heat in the extreme south, but *five to six* times greater in the extreme north.

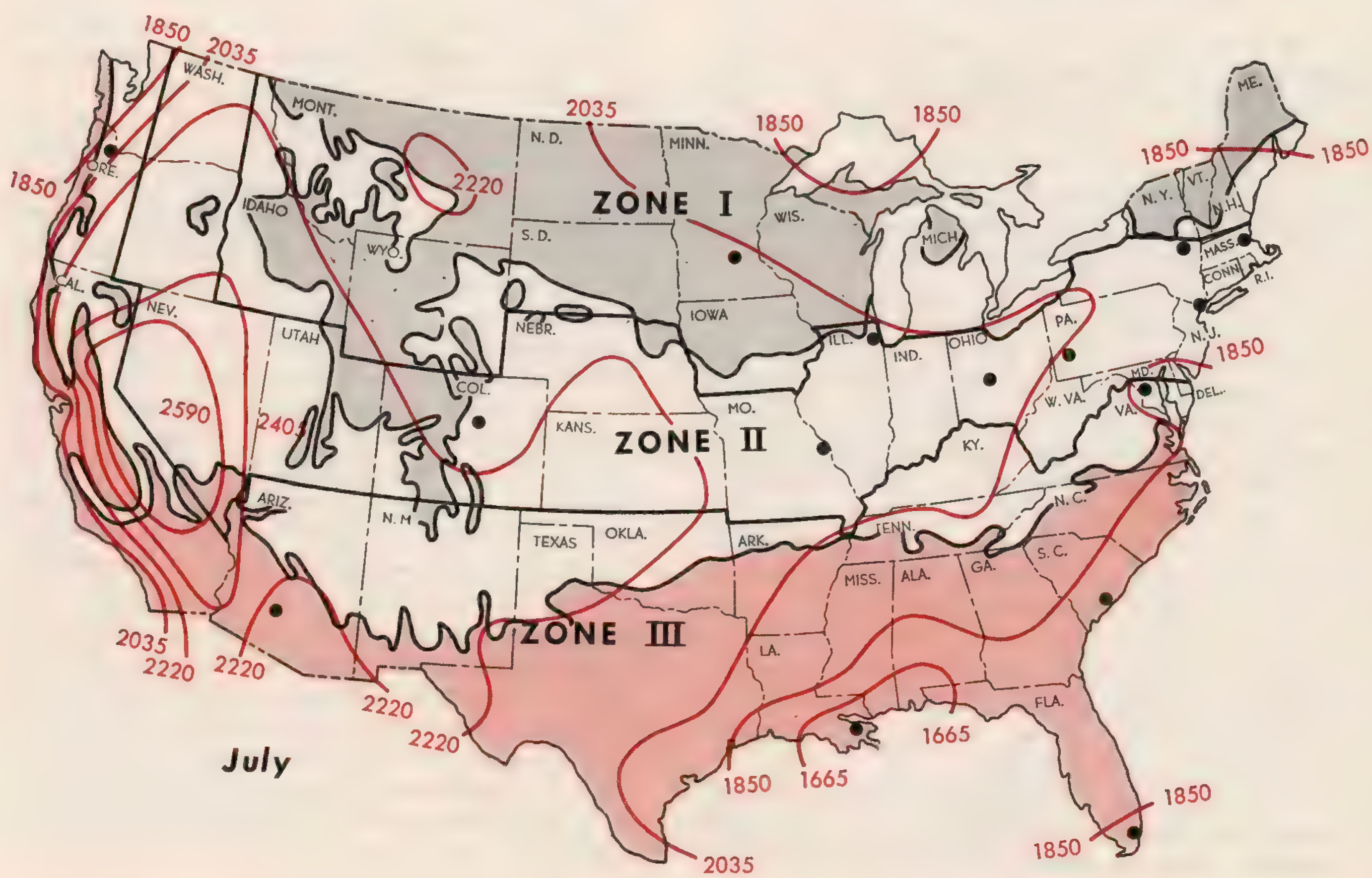
But look again: the *summer* values are practically the same, north and south! The principal difference

(*Continued on page 32*)

AVERAGE DAILY SUN HEAT ON FLAT SURFACES



These two maps show the average daily sun heat (cloudy and sunny days included) received on a flat surface in January and July. Published by courtesy of Sigmund Fritz, meteorologist, U. S. Weather Bureau.



RESIDENCE

Chicago, Illinois (Zone 1)

load	Btu/hr.	% total	% due to weather
Transmssn.	38600	48.4	48.4
Solar	15000	18.7	18.7
Lights	3500	4.3	——
People	1600	2.0	——
Ventilation	21300	26.6	26.6
Total	80000	100.0	93.7

St. Louis, Missouri (Zone 2)

load	Btu/hr.	% total	% due to weather
Transmssn.	48200	52.3	52.3
Solar	13300	14.5	14.5
Lights	3500	3.8	——
People	1600	1.8	——
Ventilation	25400	27.6	27.6
Total	92000	100.0	94.4

New Orleans, Louisiana (Zone 3)

load	Btu/hr.	% total	% due to weather
Transmssn.	29000	38.3	38.3
Solar	10200	13.4	13.4
Lights	3500	4.6	——
People	1600	2.1	——
Ventilation	31500	41.6	41.6
Total	75800	100.0	93.3

OFFICE BUILDING

Chicago, Illinois (Zone 1)

load	Btu/hr.	% total	% due to weather
Transmssn.	380000	5.8	5.8
Solar	400000	6.1	6.1
Lights	1408000	21.6	——
People	1687000	25.8	——
Ventilation	2660000	40.7	40.7
Total	6535000	100.0	52.6

St. Louis, Missouri (Zone 2)

load	Btu/hr.	% total	% due to weather
Transmssn.	475000	6.7	6.7
Solar	370000	5.2	5.2
Lights	1408000	19.9	——
People	1687000	23.7	——
Ventilation	3160000	44.5	44.5
Total	7100000	100.0	56.4

New Orleans, Louisiana (Zone 3)

load	Btu/hr.	% total	% due to weather
Transmssn.	285000	3.8	3.8
Solar	340000	4.4	4.4
Lights	1408000	18.5	——
People	1687000	22.3	——
Ventilation	3840000	51.0	51.0
Total	7560000	100.0	59.2

THEATRE

Chicago, Illinois (Zone 1)

load	Btu/hr.	% total	% due to weather
Transmssn.	84000	4.3	4.3
Solar	120000	6.2	6.2
Lights	35000	1.8	——
People	840000	43.6	——
Ventilation	850000	44.1	44.1
Total	1929000	100.0	54.6

St. Louis, Missouri (Zone 2)

load	Btu/hr.	% total	% due to weather
Transmssn.	105000	5.0	5.0
Solar	126000	6.0	6.0
Lights	35000	1.6	1.6
People	840000	40.0	——
Ventilation	1010000	47.4	47.4
Total	2116000	100.0	58.4

New Orleans, Louisiana (Zone 3)

load	Btu/hr.	% total	% due to weather
Transmssn.	63000	2.7	2.7
Solar	132000	5.7	5.7
Lights	35000	1.5	——
People	840000	36.1	——
Ventilation	1260000	54.0	54.0
Total	2330000	100.0	62.4

Cooling load analyses for three types of buildings, in three climatic zones, show how much of the total load is due to weather and how much (transmission loads) can be influenced by insulation. By courtesy of John Everetts, Jr.

Heat Control: *HEAT GAIN... the Summer problem (continued)*

tends to run from east to west except along the Pacific shore line. The greatest sun heat load is up in Montana (which gets very cold in winter) and in loops around Death Valley in California and Nevada where the sun heat reaches nearly 2600 Btu.

This intense sun heat is the heat you want to dodge if you don't air condition your buildings in summer, and is the principal source of heat you must remove if you do. It's a lot of heat.

When buildings are *not* air conditioned in summer, this sun heat is the only part of the total heat you can escape. Comfort depends on getting into protected buildings or in the shade, plus creating air motion enough to evaporate body perspiration.

When buildings are cooled by mechanical methods, sun heat on the outside surface is only part of the problem. Cooling must remove the heat given off by human bodies, by electric lights, motors and similar devices, and the heat carried by moisture in the air. It must also remove the solar heat that enters the building through windows. These cooling jobs are all in addition to dealing with the sun heat and air heat that comes in through the opaque parts of the walls and the roof.

The tables above, calculated by John Everetts, Jr., show how widely these factors can vary by type of building and local climate. In residences about half of the problem is heat gained through walls and roof (transmission load) whereas in office buildings and theaters the ventilation load is the greatest.

But that does not mean that the walls and roof are not important in these commercial structures. If such buildings were not air conditioned they would represent 40% to 45% of the whole problem, with sunny windows the balance. The wall and roof part can be reduced by insulation, the sunny windows can be shaded.

Strangely enough, the sun heat problem varies comparatively little in different parts of the United States. It varies greatly with the orientation of the buildings, the angle of the sun, the time of day and the season, as shown on page 30. Calculations of this load, in detail, wall by wall and for flat or sloping roofs, are so complex that they should be left to air conditioning engineers and experts. It is sufficient to know that for rough design purposes, roofs and east or west walls exposed to the sun and air heat are considered to reach a maximum temperature of 150° F. (although temperatures of 165° F. have been frequently observed). That is as far above the desired indoor comfort level as zero temperature is below it. Therefore, whatever insulation is used for summer comfort should be as effective as insulation designed for zero in winter.

Vapor Control

CLE CLARK, DETROIT

Vapor Control:

Water vapor is present in all buildings

In addition to temperature variations, our climate and our comfort are both greatly influenced by moisture in the air. It's something we can't see but that is always present. The only time we sense it is when it makes us uncomfortable.

Excessive moisture can cause a great deal of harm even at times when we can neither see nor sense it. It causes rot, mildew and dampness within the structure and on its surfaces. It can blister outside paints so that they fail even when relatively new. It is sometimes the cause of transient salt stains or efflorescence on brick masonry, especially in late winter and spring. It can rust out steel and iron, summer or winter, if the metal is not adequately protected.

Moisture can cause much more damage than its slight comfort benefits can offset. Generally, therefore, we seek to get rid of excess moisture in order to protect our buildings, clothing, leather and other possessions that dampness can impair, as well as to keep it from causing actual discomfort in the hot periods of our climate.

The question of whether or not moisture in the indoor air is beneficial to health is still unsettled and probably academic. Florida is considered a health resort by some; others prefer the Arizona area. One has high humidity, the other low. Neither can demonstrate superior health advantages for all people.

For many years people believed that all the moisture found indoors came from outside—through leaks in roofs and walls, or from fog or dampness entering the house on very moist days. Many good roofs and flashings have been "repaired" that never had a leak.

Now we know that our moisture problems arise from within our buildings. Most of them are man-made and thus can easily be solved. Once we fully understand the behavior of moisture, we can find ways to meet all of the problems it generates.

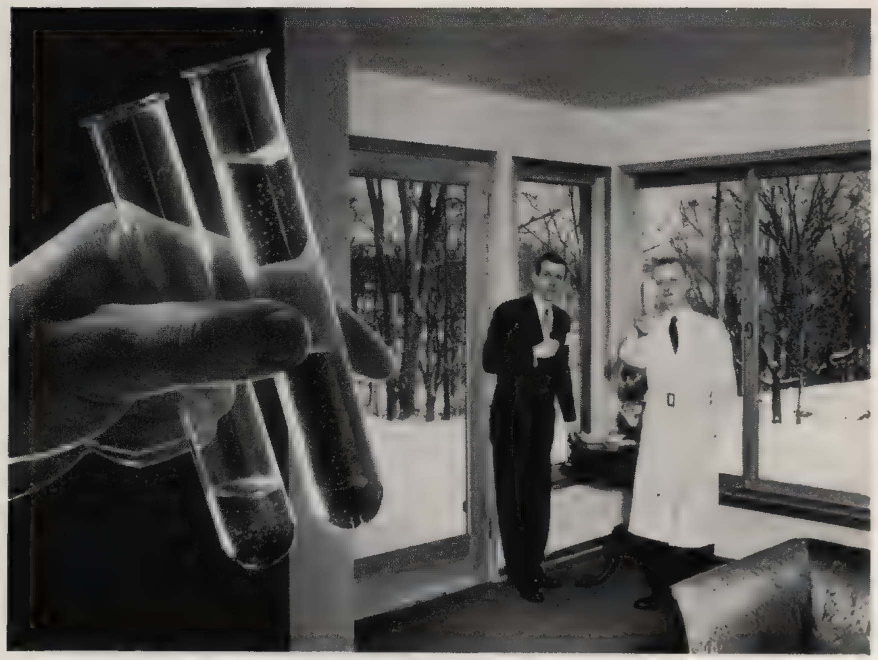
First we must appreciate that warm air can, and usually does, hold a great deal more water vapor than cold air.

(*Continued on page 38*)

A. DEVANEY, INC., N. Y.

Where would you spend your winter vacation, if you had free choice? In Florida, to enjoy the warm, balmy, moisture-laden air? Or in Arizona, to enjoy the warm dry air? Both places are fine health resorts, and this fact has stopped most of the guessing as to the health value of indoor moisture in winter.

PHOENIX CHAMBER OF COMMERCE



CLE CLARK, DETROIT

The test tubes show the moisture normally found in a generous closet full of air (about 180 cubic feet) in winter. The left hand tube contains the water the air could hold at 0° Fahrenheit when fully saturated. The other shows the five times greater quantity of water the same air would carry at 70° F. indoors when it is holding only 30% of its capacity—a fairly normal condition in houses. Multiply these quantities by 10 to get the amount of water in the air of an average living room about 12 feet by 19 feet.

The amount of water vapor present depends upon the occupancy of the building

Under identical climate conditions, a hardware store shows a "dry" occupancy, a confectioner's a high humidity level.

CLE CLARK, DETROIT

EWING GALLOWAY, N. Y.

Textile Mills: (Right) For weaving and spinning such a high moisture level is required that humidifiers are used to spray invisible mists into the air. (Above) Wool scouring and other wet processes add moisture to the air in a woolen mill.

WALTON LABORATORIES, INC.

WIDE WORLD PHOTO

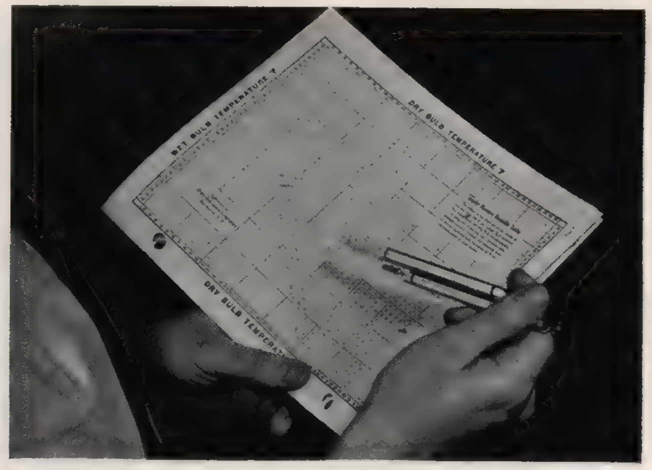
Warehouses (above) are often, but not always, relatively dry, while paper making (below) produces a very high moisture level that requires constant ventilation for control.

A. DEVANEY, INC., N. Y.

The swimming pool (above) maintains a relatively constant humidity, but a theater (below) gains its moisture from the audience, which may vary in size.

A. DEVANEY, INC., N. Y.

EWING GALLOWAY, N. Y.



Relative humidity is easily measured with a "relative humidity indicator" or "sling psychrometer". One thermometer has its bulb covered with a wet cloth, the other is dry. By whirling the device in the air, two temperatures are measured—"wet bulb" and "dry bulb". Simple tables give an exact reading in terms of relative humidity. Pocket devices cost from $8.00 to $15.00.

Gas flames generate 11 gallons of water for every 1000 cubic feet of gas burned. If not connected to a chimney or vented outdoors, this moisture is added to the air.

(*Continued from page 35*)

Thus, cold outdoor air brought into a heated building—by drafts or through open doors, or purposely for ventilation—may be carrying all it can hold while cold and yet it can become exceedingly thirsty for more moisture when it is warmed up indoors.

In dwellings we satisfy some of this thirst by water vapor released by mopping, washing, bathing, cooking, laundering, watering house plants and occasionally evaporating moisture in furnace humidifiers or water pans on hot radiators. Even perspiration adds its share.

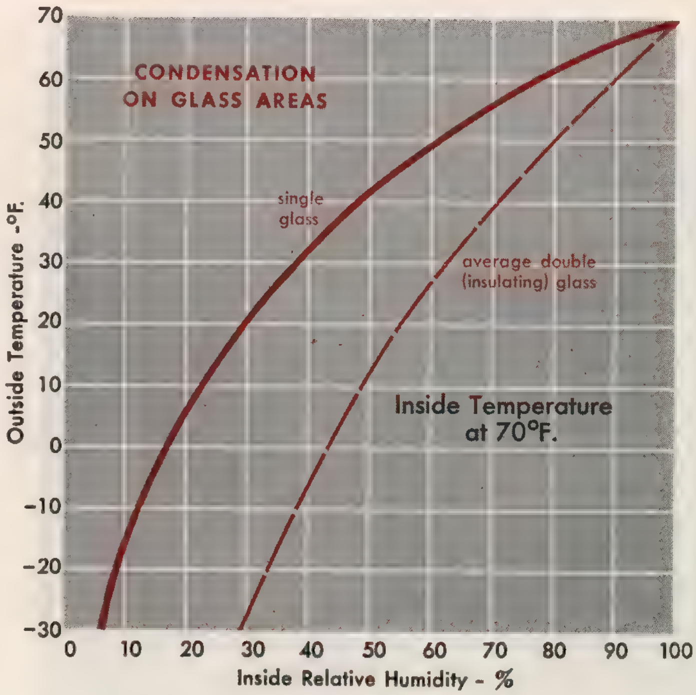
In offices, stores, theaters, industrial plants, extra water vapor may come from people—by the moisture in their breath, or from perspiration of active workers—or from goods kept in the premises. It may come from any processes generating moisture, or from the burning of fuels in open flames. In some industries devices are used to add water vapor to the air to maintain a desired high relative humidity, as is done in most textile plants.

Because warm air can hold more moisture than cold air, it becomes apparent immediately that if warm air is cooled it eventually reaches a temperature at which it is fully saturated and can hold no more. Then, if cooled a bit further, some of this moisture is squeezed out. It appears as fog or drops of water. This temperature is called the "dew-point" temperature—the point at which dew forms. The moisture squeezed out is called condensation.

The vapor in the air creates a pressure much like any other gas. The more there is, in such absolute terms as "grains of water per pound of dry air", the greater the "vapor pressure". When we want to deal with the absolute amount of water in the air we use

the automatic signal

When condensation forms on windows the indoor relative humidity is as high as it can be maintained. Don't try to pour any more water vapor into the indoor air. While people can tolerate more moisture, the building structure may develop hidden condensation as well as wet window sills. During very cold weather the appearance of frost on single glass is a good signal for cutting off humidifiers and providing ventilation. If any moisture appears on double (insulating) glass or where storm windows are used, the danger signal is flying.



this vapor pressure. When we are only concerned with how much water is in the air in relation to how much it could hold if saturated, we talk of "relative humidity".

For practical purposes it is sufficient to know that cold air, even though saturated, has a comparatively low vapor pressure. As it picks up moisture, warm air, because of its thirst for moisture when dry, quickly develops a greater vapor pressure. Warm air laden with moisture has a high vapor pressure. These differences are very real. While we cannot feel them they may be measured in terms of pounds per square foot. These pressures easily account for some of the strange things vapor can do, such as penetrate many building materials.

VAPOR PRESSURE DIFFERENCES, INDOOR TO OUTDOOR AIR—In Pounds Per Square Foot

Outdoor Temperature 100% Relative Humidity	Pressure Differences—Indoor Air At 70° For Various Relative Humidities			
	100%	**50%**	**35%**	**25%**
−20° F.	51.4	25.3	17.4	12.2
−10	50.7	24.6	16.7	11.5
0	49.6	23.5	15.6	10.4
+10	47.9	21.7	13.8	8.6
+20	45.0	18.9	11.0	5.7
+30	40.7	14.6	6.7	1.4
+40	34.8	8.7	0.8	−4.4

WINTER RELATIVE HUMIDITY RANGES
for various occupancies

DRY OCCUPANCIES: Relative humidity under 20%, closely related to prevailing outdoor RH (relative humidity) and indoor temperature.

Aircraft hangars, assembly plants (except paint shops)
Automobile display rooms, assembly shops (except paint shops)
Factories, millwork, furniture (except plywoods and finishing units)
Foundries, except enclosed molding rooms
Garages, service and storage
Shops, machine, metal working (except pickling and finishing)
Stores, dry goods, electrical supplies, hardware
Warehouses, dry goods, furniture, hardware, machinery, metals

MEDIUM-MOISTURE OCCUPANCIES: Relative humidity 20% to 45%, varies somewhat with outdoor RH but moisture content increased by indoor activities, devices or operations.

Auditoriums, gymnasiums, theaters
Bakeries, confectioners, lunch rooms, unless poorly ventilated
Churches, schools, hospitals
Dwellings, including houses, apartments, hotels. (Highest RH in kitchens, laundries, baths)
Factories, general manufacturing, except wet processes
Markets, meat, vegetable
Offices, banks
Stores, department, drug, general, with large customer patronage
Swimming pools, natatoriums, if well ventilated
Warehouses, general

HIGH-MOISTURE OCCUPANCIES: Relative humidity over 45%, not significantly influenced by climate but due primarily to apparatus or processes, or to materials in storage.

Chemical and pharmaceutical plants (RH generally controlled)
Food processing plants, most food storage
Kitchens, commercial (hotel, restaurant)
Laundries, commercial, auto, public
Malt processing
Museums, art (RH about 50% to protect paintings)
Paint and finishing shops (potentially high but usually ventilated)
Paper mills, machine rooms
Plating, pickling, finishing of metals
Public bath and shower rooms, club locker rooms
Textile mills, usually 65% to 85% RH

NOTE: The above listings are approximate only. Each project should be checked by tests in similar occupancies during severe cold weather. Within buildings of substantial size, RH may vary considerably between areas having different uses. Ventilation by natural or mechanical means may lower RH below normal expectancy.

CLE CLARK, DETROIT

EXPERIMENT 1. A block of insulation is thoroughly wetted and placed in a closed chamber containing a beaker of dry ice (CO_2) to which acetone is added to develop a very low temperature (–65° F.). The extreme cold is used only to accelerate the test. (Studio photos are used here to simulate actual laboratory test).

In a short while the cold beaker is covered with frost, the insulation is bone dry. Since the chamber allowed no other moisture to enter, the result demonstrates how moisture migrates to the coldest point (where the vapor pressure is lowest).

Vapor Control:

Water vapor behaves in strange ways

Since water vapor is a gas, like air, it obviously can move wherever air can move. What is not so easy to accept is that it can also travel through materials that air does not penetrate readily such as stone, brick, concrete, wood, plaster.

Under the very real force of the vapor pressure of warm, moisture-laden indoor air, there is a constant effort of the vapor to escape through most building materials to the colder outside where the pressure is lower.

While air does not move in the same way, there is air within these building materials (in their cells or pores) and in the hollow spaces of the structure. The vapor seeking its way out increases the moisture content of the air at each place, until, in cold weather, it may find some air that cannot absorb any more moisture. Theoretically, the vapor would begin to condense into water at that exact point.

But the strange fact, proved by numerous experiments, is that this seldom occurs at ordinary climate temperatures if the vapor can keep on moving and disperse itself in still colder air. So we find that *vapor condenses on surfaces that resist its normal flow and are colder than its dew-point temperature.*

EXPERIMENT 2. An insulation capped with a vapor barrier (as under built-up roofing) is chilled with dry ice to represent snow above the roof deck and exposed to vapor from below. Frost and ice form under vapor barrier.

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This is very important. It explains many conditions that seem to upset the theorists who do not take it into account. In a frame wall, for example, calculations as well as temperature tests show that the dew-point temperature in cold weather generally occurs in the hollow air space between studs, and about in the middle of the studs themselves. If the wall space contains, say, a two-inch or three-inch blanket of insulation, the dew-point temperature invariably is found, by calculation, to come within the insulation (as well as in the studs).

But if the insulation is porous to vapor, or if there is no insulation, neither moisture nor frost appears at the calculated dew-point zone. It appears, instead, on the inner face of the sheathing boards. These boards, being somewhat more resistant to vapor than the air space or the porous insulation, present the first surface *colder* than the dew-point that slows up the passage of the vapor.

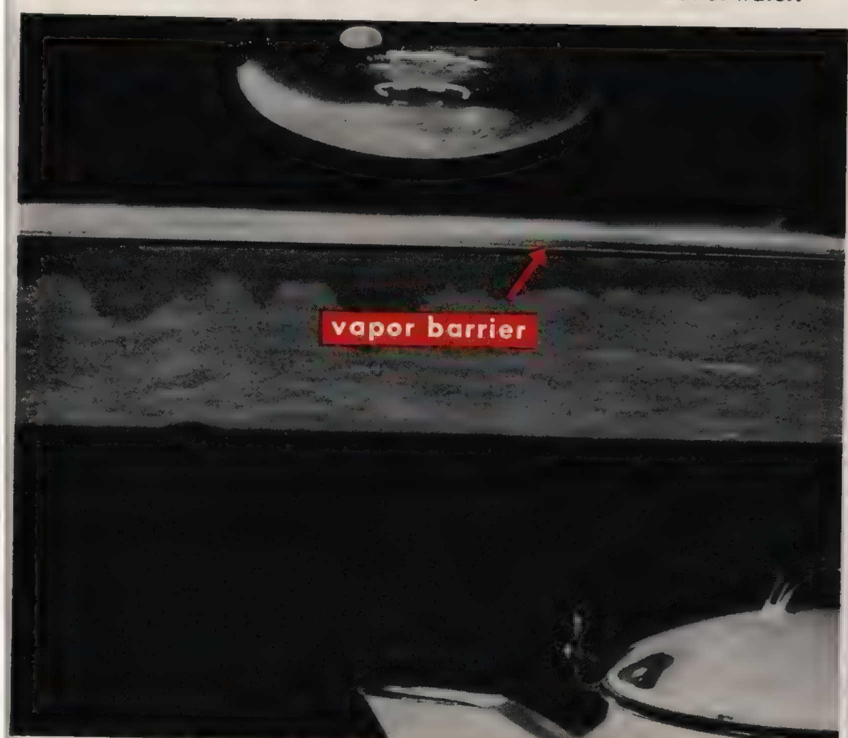
The same thing occurs if the space is completely filled with a porous insulation. But then the moisture (or later the melted frost) which gathers on the sheathing boards can wet the insulation. Eventually the water may travel by capillarity back into the insulation so that it may become damp part way or all the way through at certain times.

The experiments illustrated below show the same principle operating in roof insulation. The vapor does not condense until it reaches the cold roofing which acts as a vapor barrier. Then it may run back into the insulation. The above facts point the

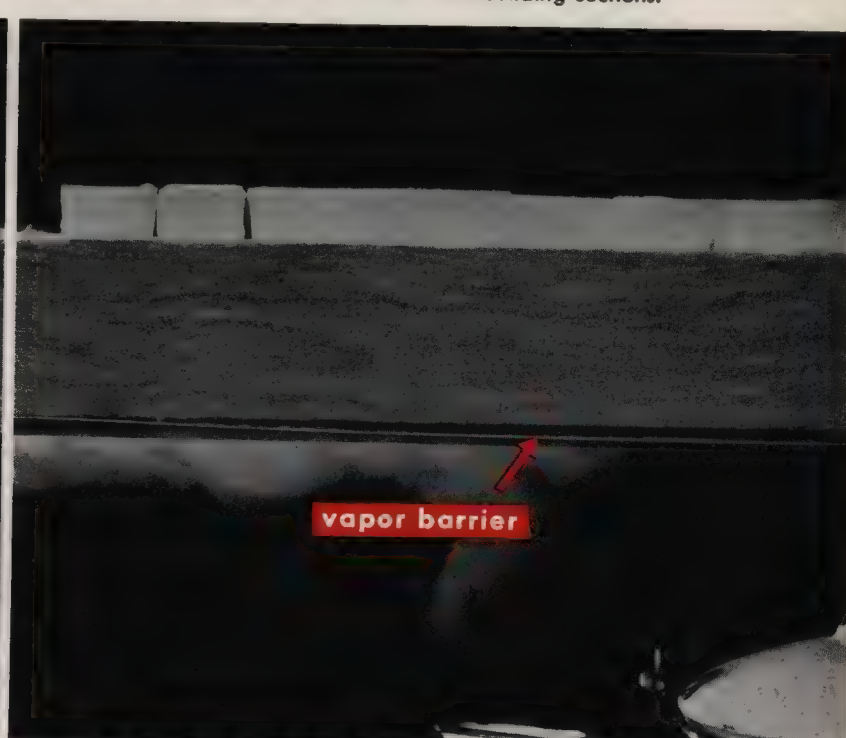
CLE CLARK, DETROIT

Vapor will travel wherever air (or cigarette smoke, above) can travel, and through many materials impervious to air. Corkboard, for example, considered vapor-resistant because its individual cells are sealed, is actually made up of compressed granules between which are many passages for both air and vapor. Most of the commonly used insulations are porous to vapor.

When the sun melts the "snow" and warms the roofing, the frost formed in the insulation melts and after the insulation is saturated, begins to drip below. While wet, any insulating material temporarily has the conductance of water.



EXPERIMENT 3. By repeating the last experiment with the vapor barrier on the warm side (near the source of moisture) no vapor gets into the insulation and hence no frost, ice or moisture is formed. This demonstrates the reason for using vapor barriers on the warm side of building sections.



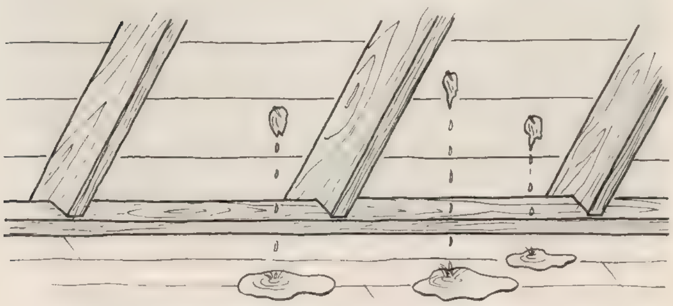
way to solving all problems involving the condensation of moisture in buildings. There are two basic methods to follow, and two alternatives for each method.

One way is to stop the passage of vapor through the structure before it can reach any resistant surface that is colder than its dew-point.

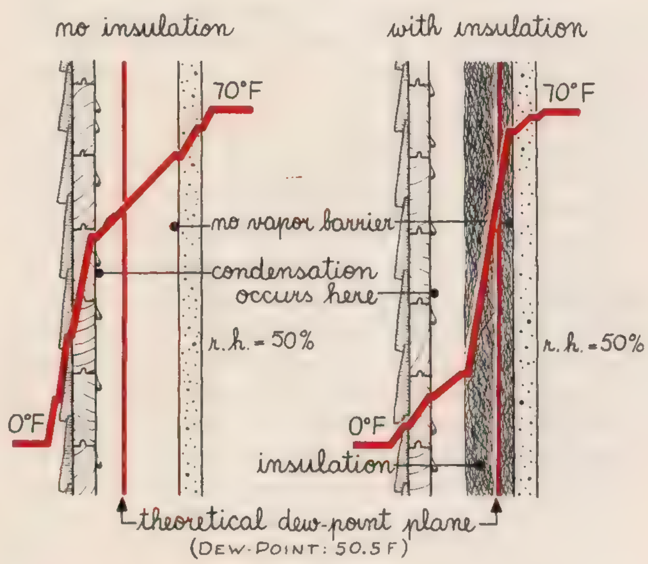
We can do that either by (1) reducing the amount of moisture indoors (thereby lowering both the vapor pressure and the dew-point temperature) or (2) we can provide a "vapor barrier" or a vapor resistant surface on the warm side of the dew-point zone.

Another basic way is to let whatever vapor gets into the building materials keep on flowing to the colder air without impeding its flow. Under these conditions it will not condense.

We can do this by (3) actually venting the cold side to the outer air, as in some of the "air-cooled" walls and roofs described later, or (4) simply by using materials on the cold side that are at least five times more porous to vapor than those assembled on the warm side. The "five times" is arbitrary, but observation shows it provides a reasonable margin of safety, even in the cold-climate zone.



Excessive water vapor in cold, inadequately ventilated attic spaces often forms ice "walnuts" on the ends of shingle nails. When the sun again warms the roof the ice melts, wetting the floor and often the ceiling below.



Although the theoretical dew-point temperature zone, where condensation should occur, is always in the air space, or in the insulation and near the center of studs, the moisture actually appears first on the inner face of the sheathing.

HOUSING AND HOME FINANCE AGENCY

Test panel, one of many studied in government-sponsored research, shows frost formed on the sheathing.

FOREST PRODUCTS LABORATORY

When indoor moisture reaches a vapor-resistant paint film, it may form water blisters that destroy the paint.

CLE CLARK, DETROIT

It is easy to be confused about the vapor resistance of different materials. Plywoods (1) depend largely upon the type of glue or resin used in their manufacture; those with certain resin films are highly vapor resistant; others, relatively vapor porous. Sheet metals (2), metal foils, if free from pin holes (6), and sheet glass (8) are perfect vapor barriers. Among paints (3), rubber base, aluminum and lead exterior paints are vapor barriers; most other common paints are marginal or porous. Asphalt mastics (4), if fibrated, are generally vapor porous; if not fibrated, they are usually vapor resistant. Glossy coated asphalt papers (5), asphalt laminated papers without cotton or jute reinforcement and foil laminated papers are highly vapor resistant. Dull-surfaced asphalt or tar "saturated" papers (7, 11, 12, 13, 14) are water-repellent but not vapor resistant; they are good for exterior sheathing papers but not for vapor barriers. Almost all plastic films (9, 10) are somewhat porous to vapor, but polyethylene and certain others are satisfactory vapor barriers. Manufacturers should be asked to rate their materials in the newly adopted term, "Perms", which is water vapor transmitted in grains in one hour, through one square foot of material, when the vapor pressure difference is equal to a one inch column of mercury. A material having a vapor transmission rate of one perm or less is considered a good vapor barrier.

Vapor Control: *Condensation is evidence of faulty design, assembly, or control*

Now that these facts are known, and we have at least four ways to prevent condensation in buildings, there is no more reason to build structures that develop internal dampness than there is to build a roof that leaks from the day it is finished.

Condensation is evidence of either faulty design, the faulty assembly of materials if the design is sound, or of improper control of generated vapor.

Every building that shows internal or hidden dampness due to condensation is violating one or more of the known principles. Fortunately, almost every such building can be corrected by their proper application. Only in very rare instances is the trouble too deeply rooted in improper design to permit the use of corrective measures at a reasonable cost.

While the correction of existing difficulties may require the judgment of experts because so many obscure factors may be contributing to the conditions, *it is not difficult to design and erect new buildings that will be entirely free of condensation problems.*

The first step is to recognize the moisture level that will exist within the building—whether naturally by reason of the nature of the occupancy, or by intent as in the case of textile mills and certain processing industries. If the owner or client does not know in advance what relative humidity may prevail indoors during cold weather, or if the table on page 39 is not a sufficient guide, tests should be made in similar occupancies. This can be done with a "sling psychrometer" or relative humidity indicator, the use of which is illustrated on page 38.

The second step is to select or design wall, floor, and roof-ceiling constructions that will permit the maintenance of the desired moisture level without likelihood of developing hidden or visible condensation. This is usually a matter of the proper location of a vapor barrier.

To simplify this step new "occupancy-moisture" ratings are given in Part II for all common constructions, and methods of checking any other designs are explained on page 112.

Some constructions provide for the easy installation of a vapor barrier; others do not. When the vapor barrier is not easy to install or when the quality of workmanship to be obtained implies that there may be considerable leakage, then one or more of the other preventive steps should be considered in addition.

It may be stated that *all new buildings erected in Zone I, most buildings in Zone II, and all buildings in Zone III which have a high moisture level indoors, should be built today with a vapor barrier material installed as near as practical to the warm interior faces, whether or not the building is insulated.*

The exceptions are in Zones II and III only. In Zone II buildings permanently destined for "dry" occupancies may be built without a vapor barrier if the exterior construction is reasonably porous to vapor or is actually vented. A vapor barrier will do no harm in any building but in Zone III if extra cost is involved, judgment may be used to determine the need, based not only on the occupancy-moisture factor but also on the time factor as noted later.

A. DEVANEY, INC., N. Y.

Rentable space should be designed for almost any occupancy. The store rented for this self-service laundry, which produces a high moisture level, might have been originally intended for a dress shop or some other normal or "dry" occupancy.

Here in this apple-butter factory, the excess moisture is carried away by a large ventilating fan and by hoods and vented stacks over the cooking kettles. This confinement and removal of water vapor creates better working conditions in the plant.

Many condensation difficulties occur during the first period of occupancy because the builder provided insufficient ventilation during construction to carry off the tons of water used in concrete work, poured gypsum roof slabs, masonry mortars and plastering. The "salamanders", used indoors during winter operations, add to this moisture with their products of combustion. Even the normal ventilation provided for future building use is not enough to relieve this excessive moisture; every possible opening should be used for as long a period as the job progress permits. In freezing weather, openings may be covered with vapor-porous paper or muslin to serve as wind-stops, and sufficient heat supplied to prevent frost damage.

EWING GALLOWAY, N. Y.

When it is impractical to provide a vapor barrier under conditions where its need is indicated, attention should be given to the other alternatives:

1. Can the indoor moisture be lessened by fans, blowers or other means of ventilation?
2. Can the indoor moisture level be lowered by eliminating unnecessary sources of moisture, such as damp basements or crawl spaces, or the direct venting of moisture-producing units such as laundry dryers, steam tables, spray booths? Obviously the moisture contributed by humidifying devices can be eliminated.
3. Can the exterior walls and roofs be directly vented to the outer air? See the discussion of air-cooled walls and roofs on page 56.
4. Can exterior surfacing materials be selected which will be substantially more porous to vapor movement than the materials used on the interior side?
5. Can the interior surfaces be treated or finished to increase their vapor resistance substantially?

Since the first two alternatives are governed by the operation of the building, we can modify our first statement and say, "Condensation is evidence of faulty design, construction, or *operation* of buildings".

How the last three principles are applied to the insulation of existing buildings, or to those parts of new buildings that can best be insulated with pneumatically installed or hand-placed "fill" and "poured" materials, is explained on the next page.

A. DEVANEY, INC., N. Y.

Clearly visible on the shiny ceiling above this newsprint machine, is condensation—evidence that (1) the monitor ventilators are not adequate (perhaps not opened enough) and (2) the roof over the flat ceiling is inadequately insulated for the prevailing climate.

Most older houses have larger volume, more windows, fewer baths per occupant than modern homes. The vapor concentration is so low that condensation problems are rare.

More modern houses are comparatively small in volume per occupant, tightly constructed, use more water in baths and laundries and thus require greater care in vapor control.

Vapor Control: *How fill insulations can be used without vapor barriers*

Every now and then scientists appear to contradict themselves. Here is such a case:

On the one hand, the high value of a vapor barrier on the warm side of floors, walls, and ceilings has been demonstrated as a means of eliminating the hazards of hidden condensation.

On the other is the fact that hundreds of thousands of existing buildings, mostly dwellings, have been insulated by blowing mineral wool into the hollow walls, or blowing or pouring insulating materials across attic floors, without installing a vapor barrier. And less than 3% of these jobs have developed evident dampness due to condensation, even in Zone I.

How come? Is this a sales trick or can it be reconciled?

The scientists are not contradicting themselves nor are the sales people trying to deceive their customers. In fact, if the 3% or less of buildings that have shown dampness difficulties had been properly handled, they would have remained at least as dry as they were before insulation was installed.

The answer lies in the application of the "cold side venting" principles described in the preceding pages—plus the fact that most older buildings, particularly homes, are not built as vapor tight as modern buildings, nor is the vapor generation so great in proportion to volume or air leakage.

When mineral wools are "blown" into side walls, the blow holes cut in the sheathing are never closed tightly but are covered with a vapor-porous paper (or nothing at all) before the outside finish is restored. These holes, plus the cracks between well dried out sheathing boards usually provide sufficiently low resistance to vapor to keep it from condensing.

When the outer construction is known to be vapor resistant because many coats of paint have formed a tight seal, or vapor-resistant sheathing papers were mistakenly used, additional vent holes should be provided near the top and bottom of the stud spaces. Lapped siding can also be wedged out to break the paint seal at these points, as shown at the right.

In attics and lofts, blown or poured insulations should never be installed without adequate permanent ventilation. Federal Housing Administration recommendations (and in some areas, requirements) are shown in the table on page 63. This venting allows vapor that penetrates the ceiling to be carried away harmlessly. It also increases summer comfort.

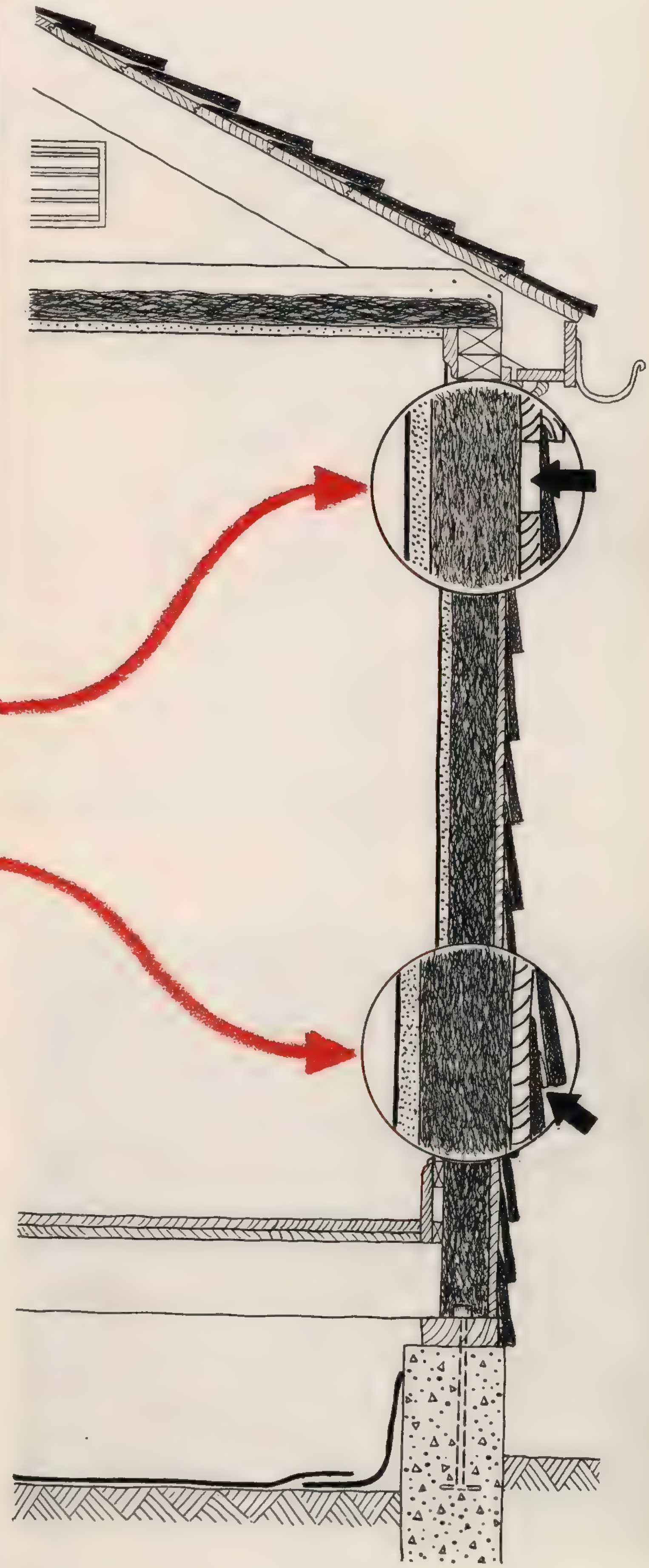
These measures have proved adequate in the great majority of cases, unless there is an excessive generation of moisture within the buildings. Frequently damp basements or crawl spaces, or unvented gas space heaters and ranges, or the use of humidifiers on furnaces or radiators, are found to be the true causes of excessive moisture. Then increased ventilation or the elimination of sources of dampness will usually correct all difficulties.

Another treatment, usually reserved for difficult conditions, is to treat the exposed warm faces of walls and ceilings to greatly increase their vapor resistance. Rubber-base plaster sealers and interior paints, aluminum paints and white lead and oil paints, in two or more coats, create excellent vapor barriers. These may be applied to the inner face of all exterior walls and to the under side of the top floor ceiling as a final corrective. Original decorative treatment can then be restored over these films where necessary.

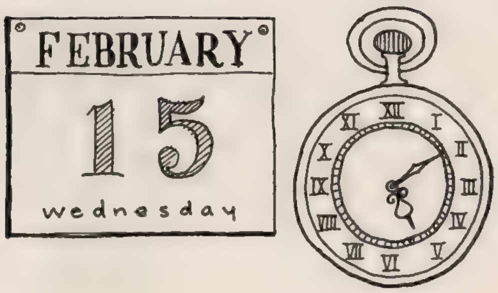
Thus, if the principles of vapor movement are understood and applied, winter condensation can be prevented or eliminated even when vapor barriers cannot be installed within the structural enclosures.

When existing buildings are insulated with mineral wool using the pneumatic method, skilled operators always leave the "blow-holes" covered only by the outer finish. This provides a vapor relief spot in every insulated area.

In addition, when the outer finish is vapor tight, as with multiple paint layers in good condition, the skilled applicator cuts the film under the siding and inserts "toothpick" wedges to allow vapor movement. Wedges are placed as near the bottom as practical and spaced in the center of each stud space.



Vapor Control:



TIME . . . is an important factor

Things don't happen all at once in the effect of climate on buildings. Nature seldom produces the same weather for long periods. Some buildings may not be occupied, and thus have the same interior conditions for 24 hours a day, every day of the year.

These variations influence the solution of many moisture problems. And because there is little data to guide us, judgment must be exercised.

It takes time for wood to be weakened by rot. Even under adverse moisture conditions which keep a wood roof, say in a textile mill, almost constantly above the safe 16% to 20% moisture content, it may be five or ten years before the roof must be replaced.

Or compare two insulation materials, one absorptive of moisture, the other not. If condensation occurs in a roof insulated with an absorptive material, it may not show any dripping for weeks or months, because the water is held long enough so that intervening drying conditions may occur to prevent super-saturation. The non-absorptive insulation will drain out its condensation quite rapidly, hence dripping may occur early. While this seems to favor the absorptive material, it actually does not, because when either type is wet, its resistance to heat flow almost vanishes; therefore the material that dries rapidly restores its insulating value faster. Also if a wet material is subject to rot or decay, the long-time dampness diminishes its life.

ULRIC MEISEL, PHOTO ASSOCIATES

Buildings which are occupied only for parts of the day, and not even all week, like schools, churches, offices, are likely to have widely varying moisture levels which may or may not coincide with hourly extremes of climate.

CLE CLARK, DETROIT

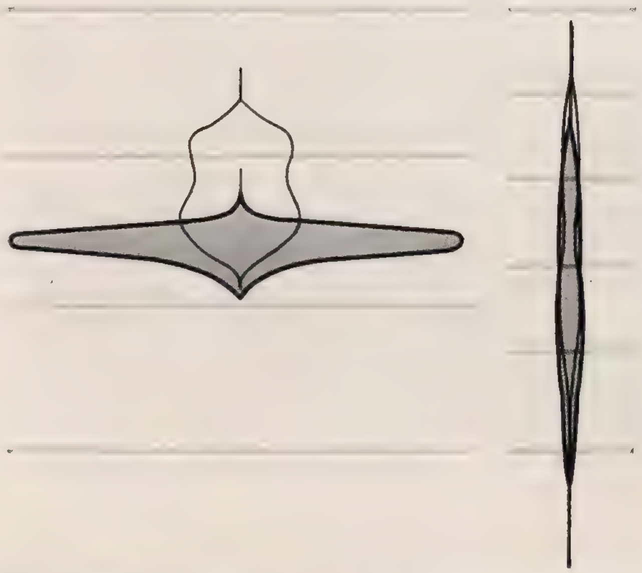
An insulation material, such as some vegetable fiber boards, that can absorb and hold water is slow to reach the saturation point. Its sponge effect delays dripping—sure evidence of destructive leakage or condensation.

Similarly, compare a natatorium to a church, grade school or theater. The swimming pool water is there for weeks, months, or years at a time; the relative humidity above it is not greatly affected by the length of time people use the pool. But grade school hours are seldom over 40 per week out of the total of 168 hours; a church may be occupied scarcely ten hours a week.

When temperatures are lowered at night, or when the buildings are not occupied, new conditions exist. Condensation may occur in rare cases during these cold periods, though not during normal occupancy.

Data on the duration of extremes of weather are not yet available for design purposes. We usually must design, not for the greatest heat or cold, but for the worst conditions that come often enough to be worth countering with heating or cooling systems. Here the designer must exercise judgment.

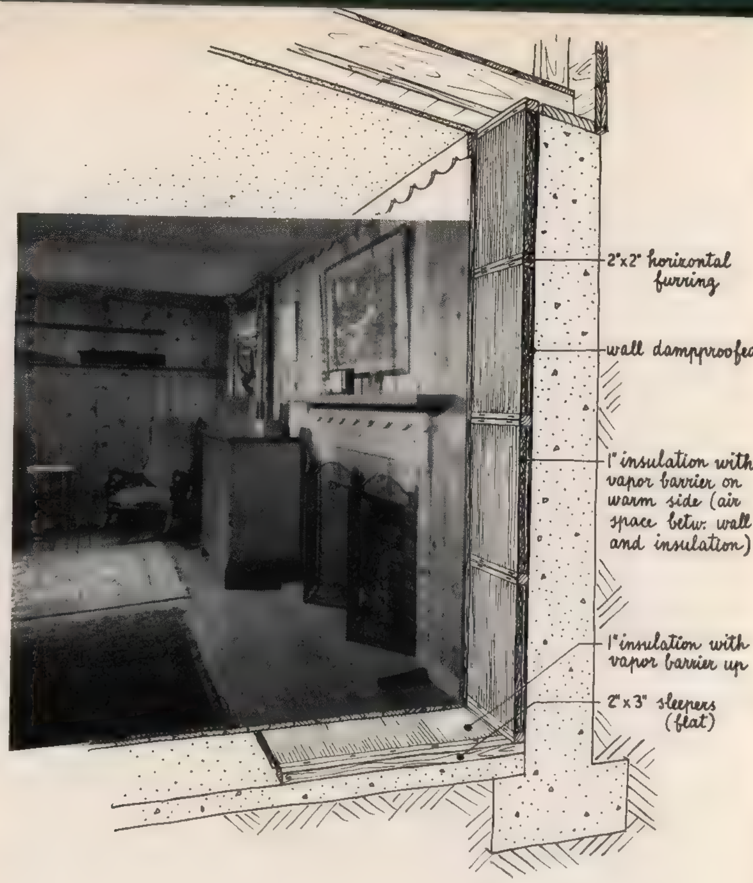
The same thing applies to the use of vapor barriers or other means of preventing condensation. In the thermal analysis charts presented in Part II the temperature and occupancy-moisture conditions are assumed as in a steady state at "design" temperatures and humidities. These may or may not exist for long periods. Therefore, when the duration of severe conditions is not great, the designer may elect, on his own judgment, to assume that the steady state conditions for a milder climate zone will provide adequate protection against short-time extremes.



The probable duration of high dew-point temperatures outdoors can be approximated by the width of the "leaves" in the Siple charts that deal with moisture. However, data on frequency and duration of troublesome climatic conditions are still meager. The shaded areas are dew-point temperatures (reverse of charts on page 12). Left diagram shows a very humid summer condition typical of the Gulf Coast. Right, a humid condition all year.

Non-absorptive insulations, such as most mineral fiber products, hold little water from leaks or condensation and show dripping early. This is advantageous because wet insulations do not insulate until dried again.

The humidity level in some buildings, such as a natatorium or an industry operating 24 hours a day, remains practically constant, with only external climate conditions changing. See the school picture opposite.



Dampness on cellar walls, especially in spring and summer, is due to moist air reaching cold surfaces. Ventilation aggravates the condition unless the air is dry. Where space is occupied, one good answer is insulation plus a warm-side vapor barrier on walls and floors, to keep moist air from contact with cold masonry.

Vapor Control:

Summer condensation . . . and "reverse flow"

HHFA PHOTO

Crawl spaces never get the benefit of drying sunshine, and are commonly damp. A ground cover of roll roofing (simply laid over the bare earth with edges lapped 3" to 6") plus adequate ventilation, are the principal correctives, but summer condensation requires steel to be well protected.

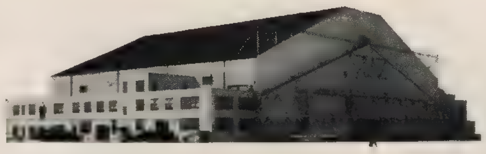
Except in a few favored areas, the heat of the summer season in the United States is accompanied by uncomfortably high humidity. It is the presence of this mass of water vapor in the air that causes summer condensation in buildings, fog over cool valleys and fields, dew on the early morning grass, and sweat on glasses and pitchers containing cold summer drinks.

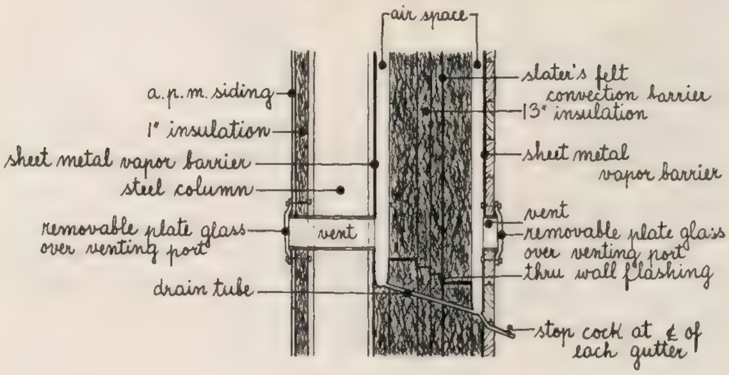
When the relative humidity is high it may take only a few degrees drop in temperature to bring the air to its saturation point. Wherever lands and people are blessed with cool night air following hot humid days, almost anything that conducts heat rapidly, like masonry and the metals, is likely to be dampened by the condensation we call dew.

You see it in the cool basements and cellars of buildings, especially on humid spring and summer days. The masonry surfaces are cooler than the dew-point temperature of the outdoor air; hence when such air reaches them, vapor condenses to water on them. You cannot cure this condition by ventilation unless the outdoor air is quite dry. The more moist air you bring in, the more moisture will collect. To prevent this form of dampness you should shut out the warm outdoor air, or heat the cellar surfaces, or use air drying devices (dehumidifiers), or install a vapor barrier (usually with some insulation) to keep the damp air away from the surfaces.

Shaded places, which perhaps never get the summer sun, are often damp from this cause. Crawl spaces under houses or other buildings are real trouble-spots in summer, especially for metal beams or joists or metal ventilator grilles and frames. If these are of iron or steel and are not well protected against moisture, they can rust severely in a few years.

A problem that puzzles many people is what happens when you air condition (and cool) a building in summer. Isn't the vapor barrier designed for winter





protection then on the wrong side? Won't the flow of vapor reverse itself and come in from the warmer outside air? Won't the vapor barrier collect moisture?

The "reverse flow" of heat and vapor is a real problem in certain specialized buildings. Structures like the huge aircraft testing hangar at Eglin Field, Florida, where indoor climates ranging from –65° F. to extreme tropical heat and moisture can be created at will, must be built with two vapor barriers, each arranged with ports so that the side which is warm can be made vapor tight while the cold side is allowed to breathe. Certain types of storage for vegetables which must be kept above freezing but below outdoor summer temperature also require special design.

In normal occupancies the story is different.

Comfort air conditioning seldom is designed to reduce dry bulb temperatures more than 15° F., rarely 20° F. Cooling is usually needed for only a few hours a day. Because the temperature difference is not often large enough to reach the dew-point of the warm outside air, and because if it were the duration of these extreme conditions is brief and intermittent, it is *not* necessary to provide vapor barriers on the outside of most buildings in summer.

If condensation does occur, say in the late afternoon when the load is heaviest, conditions will be relieved after dark and the moisture will evaporate.

Furthermore, the only areas where extreme heat and humidity appear together for long periods, day and night, are in the Gulf area of Zone III, where no vapor barriers are normally required in winter.

Even in Florida and parts of western Oregon and Washington where dampness in frame buildings has been charged to reverse flow, reports of experts indicate that horizontally driven rain and other factors are the probable cause.

Thus for all practical purposes there is usually no design problem due to the reverse flow of vapor.

USAF AIR MATERIAL COMMAND

Certain highly specialized buildings, such as cold storage buildings or the Air Force testing hangar at Eglin Field, Florida, may require special vapor barrier design. Here extremes of climate, from an arctic –65° F. to a hot desert sandstorm at 150° F., can be produced on demand. To meet these conditions 13 inches of insulation was located between two hermetically sealed vapor barriers separated from the insulation with air spaces. Special ports were provided so that either side, when colder than the other, could be vented while the warm side remained sealed.

CARRIER CORPORATION

Comfort air conditioning in summer rarely produces cooling of more than 15° F. below outside air, and then only for a few hours a day. Both the time element and the slight temperature difference make it unnecessary to provide vapor barrier protection against reverse flow.

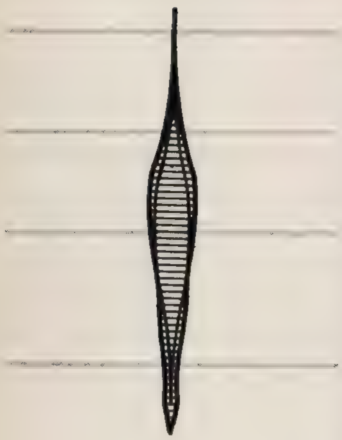
SAMUEL CHAMBERLAIN

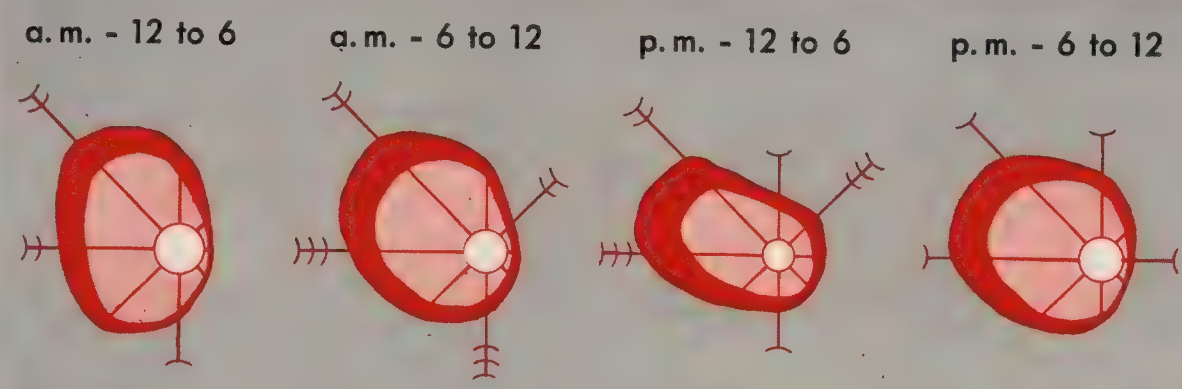
Vines constitute one of nature's automatic cooling devices. The leaves provide shade. Evaporation of moisture from their surfaces cools them. The combination is ideal for sunny walls in hot weather. This is Standish Hall at Harvard University.

Structural Ventilation:

(For Summer comfort and Winter vapor release)

January





WINTER WINDS are often strong and frequent (solid red) and add to discomfort or increase heat losses from buildings by the effect called "wind-chill". Periods of calm (white) are of short duration. These charts are selected examples, not national averages. Your climate may be different.

Wind-chill is the apt name applied to the combination of wind and cold. It is not only most uncomfortable to man but draws more heat away from buildings than still air.

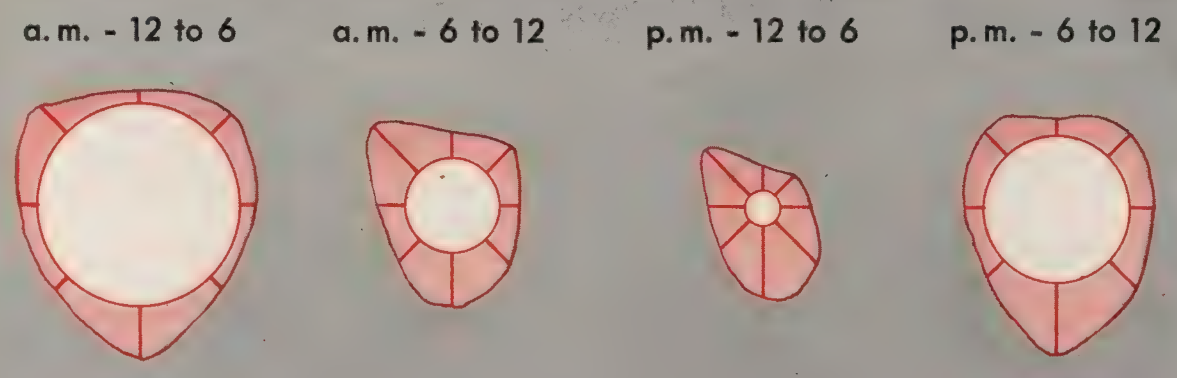
A. DEVANEY, INC., N. Y.

Ventilation:

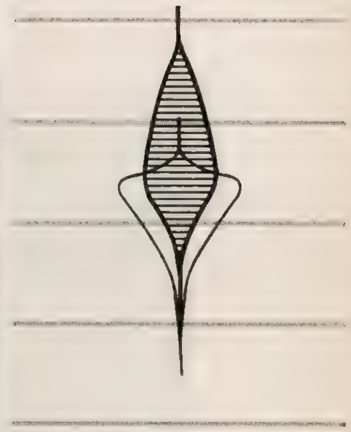
How wind movement affects comfort

Dr. Siple, who originated these weird looking diagrams, likes to call them "ham steaks". Once you learn how to use them, they tell an important story affecting the design of buildings and their effective insulation for economy and comfort.

They tell the facts about wind movement. The center "bone" represents periods of calm air (up to 3 mph). The irregular shaded space around this bone—which might be called the meat—shows not only the time period but also the direction from which winds 4 to 15 miles per hour are blowing. The red outer "rind" around the meat does the same for winds from 16 mph to 31 mph. Beyond the rind are "skewers" or lines with arrows, measuring the direction and velocity of extreme winds.



SUMMER CALMS (white areas) usually predominate over mild winds or gentle breezes (shaded) during night-time and morning hours. Some relief is provided by afternoon showers or thunderstorms, but winds are often lacking when we need them most for comfort during the hottest part of the day and early evening.



August

These "ham steaks" are an improvement over the "wind roses" formerly used by climatologists to record wind velocities and directions because the latter only showed wind direction and velocity, neglected the calm periods.

Now look at the temperature-humidity curves related to these wind charts. What you will see from these selected examples is that in winter, when it is very cold, there may be high or moderate winds and little calm during hours when it is likely to be the coldest. And in summer, especially in late afternoons when sun heat is at its worst, we are as likely to get calm air as cooling showers or breezes.

Wind-chill is the appropriate name for the combination of wind and cold. The surface film of air that helps to "insulate" all materials is diminished by high wind movement, is most effective in still air. Thus the sides of a building exposed to prevailing winter winds require more insulation or equivalent protection than the sides in the lee of such winds.

In warm weather, air movement helps cool our bodies both by convection and by the evaporation of perspiration. We welcome it, but we need it most when it is hot and humid. Dr. Siple's complete charts mentioned on page 12 also show how much air movement is required with different vapor pressures (or relative humidities at stated temperatures) to attain equal comfort.

In this respect buildings are somewhat like people. If winds or breezes are blowing, the surfaces of the building can be kept cooler. More importantly, these air movements can be directed, by the design of walls and roofs, to carry away much of the unwanted solar heat. We call them air-cooled walls and roofs.

Breezes are welcome in summer. They make hot sun and high humidity both tolerable by carrying away more body heat, and cooling the skin by evaporation.

A. DEVANEY, INC., N. Y.

U. S. ARMY PHOTO

Admiral William F. Halsey's house at Munda, New Georgia, Solomon Islands, shows a "native" interpretation of the shaded, air-cooled roof. Note also two types of walls for hot climates: at left, sand-bags representing the massive wall, and in the main house, exceedingly light construction.

Ventilation: *Air-cooled walls and roofs improve building performance*

No explorer or hunter would think of traveling in hot country without equipping his tent with a "fly" to shade it from the blazing sun.

Nor would he pitch his tent in the sun if he could find a safe spot in the shade of a tree.

You and I instinctively do the same thing—we prefer the shade of a tree or building to direct exposure to hot sunlight (at least after we have acquired a healthy-looking tan).

Buildings themselves can be more comfortable if similarly shaded from sun heat. Ivy growing on a sunny wall contributes such shade and, by the evaporation of moisture from its leaves, actually lowers the temperature of the adjacent air.

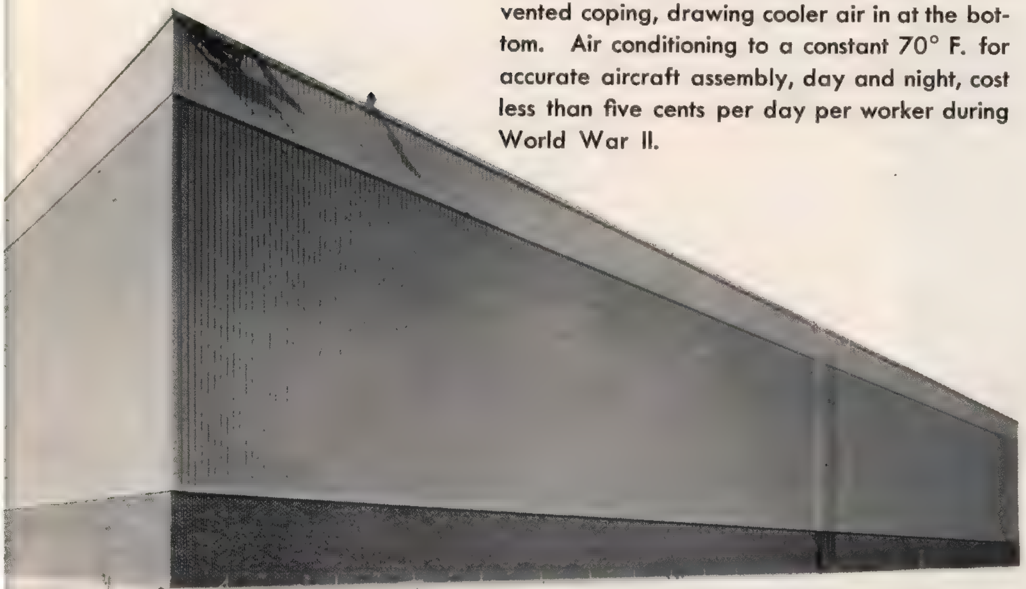
When this idea is accepted as a design principle, buildings can be built with their own sun shades! Actually a considerable number of buildings, some of them very large, have demonstrated the practical value of shaded—and air-cooled—walls and roofs.

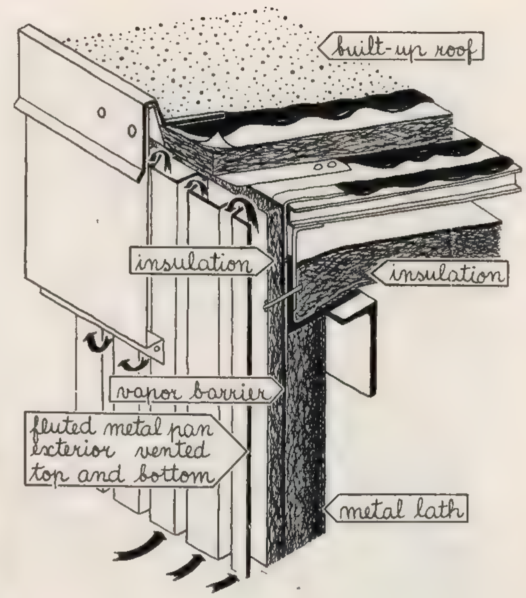
The principle is obvious; its application not so clear and simple. In walls it means an outer shell enclosing a vertical air space vented at the bottom and top. This shell receives the sun's heat. It warms the air in the vented space. The warm air rises, drawing in cooler air at the bottom. The air carries away most of the sun heat, leaving only the component that radiates across the vented space to the main mass of the building. Whenever possible the vented air space should be enclosed with non-combustible materials or the bottom openings screened with heat-conductive metal to check flames (on the "Davy Lamp" principle); otherwise the draft might spread fire rapidly.

In roofs the tent fly explains the idea. The exposed top deck, whether sloping or flat, receives the sun heat. Beneath it is an attic or loft, freely vented at eaves, sides, ridge or wherever vent openings can be placed. As the air is heated it seeks to escape out of these vents, drawing in cooler air. Better still, is to place the vent openings so that every breeze that stirs will force out the heated air. When gravity flow or reliance on winds is not enough, ventilating fans or blowers will produce positive results.

(*Continued on page 59*)

Two huge aircraft plants (Fort Worth and Tulsa) have air-cooled walls like this. Sun heat warms the air in the flutes. It rises and escapes at the vented coping, drawing cooler air in at the bottom. Air conditioning to a constant 70° F. for accurate aircraft assembly, day and night, cost less than five cents per day per worker during World War II.

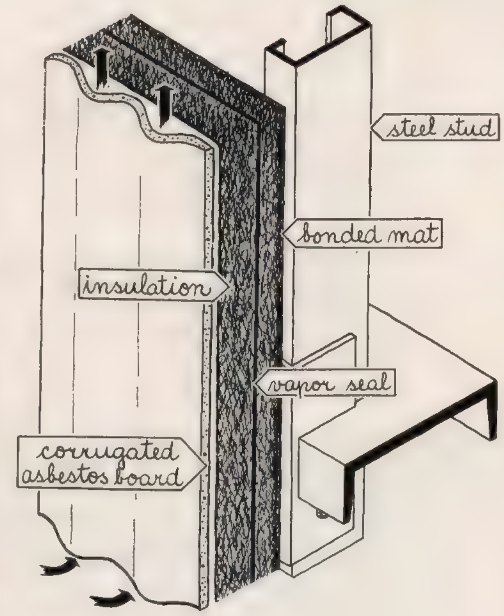




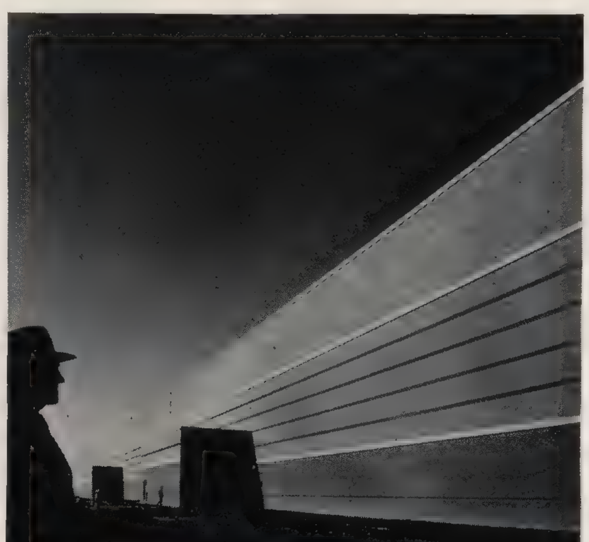
THE AUSTIN CO., ENGRS. & BLDRS.

When steel was scarce during World War II, this plant at Marietta, Georgia, was surfaced with a ventilated asbestos - cement siding. Note air-space between insulation and siding and the vapor barrier located so that the inner layer of insulation could serve as an acoustical (noise-absorbing) treatment. Each of the buildings on this page was approximately 4,000 feet long, 65 feet high, and 250 to 350 feet wide.

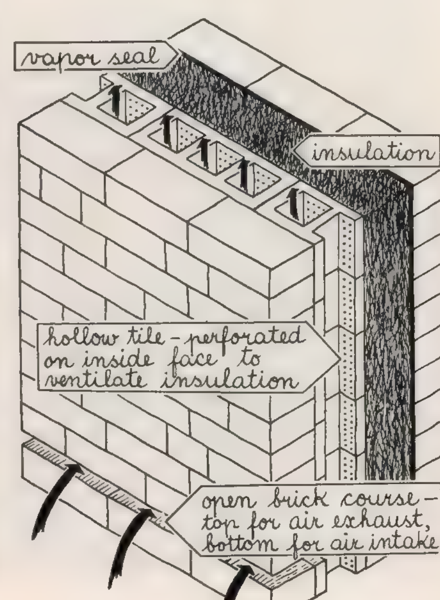
ROBERT & CO.



Another alternate to avoid use of steel was an all-masonry, self - supporting curtain wall, 65 feet high, used in the aircraft assembly plant built at Oklahoma City. Here the ventilation (and drainage of the outer surface) was accomplished by hollow tile set with channels vertical and vented through special units at top and bottom. The tremendous heat-absorbing capacity of this great mass of masonry was partly offset by this automatic removal of most of the sun's heat.



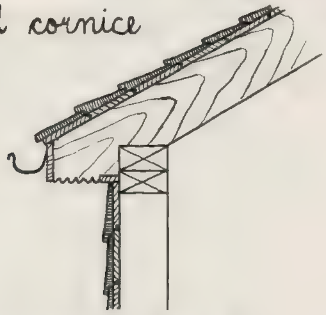
THE AUSTIN CO., ENGRS. & BLDRS.



Common types of vents

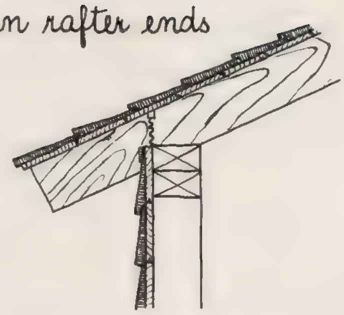
Eave vents – Frame roofs

closed cornice



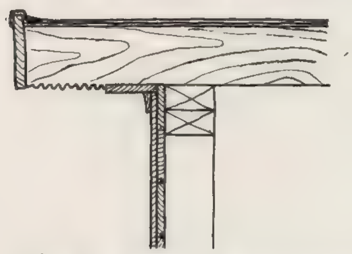
tack screen strip to ends of rafters before applying fascia and soffit. Leave 1" or more continuous vent

open rafter ends



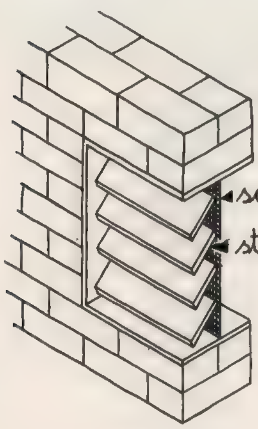
tack or staple screen between rafters to roof board and sheathing

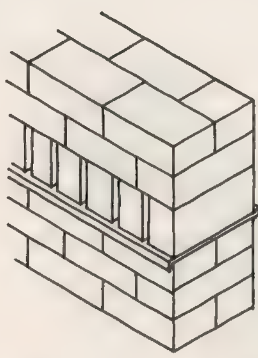
shed or flat roof overhang



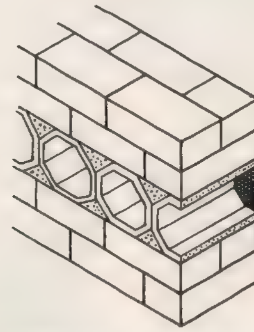
tack strip of screening to ends and underside of rafters before adding fascia and soffit board

Wall vents – Masonry





open vertical joints in masonry – possibly in soldier or rolok course

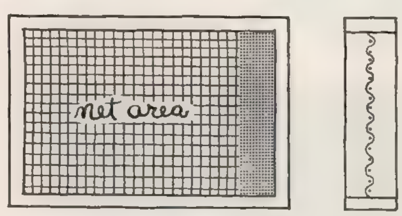


hexagonal or round tile used decoratively screened at back – use small units to avoid bird-nesting

Gross area and net free area of vents

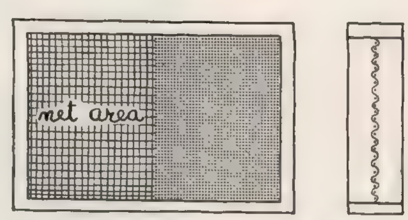
1/4" mesh hardware cloth only

gross area = net area



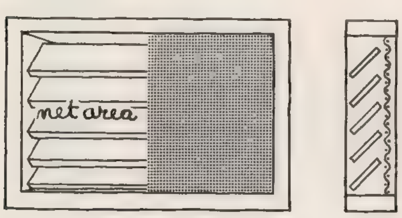
1/8" mesh only

gross area = 1 1/4 times net area



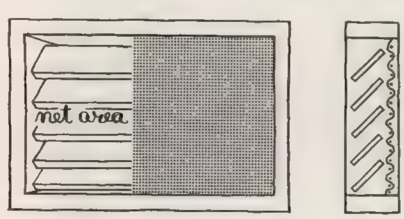
1/16" mesh insect screen only

gross area = 2 times net area



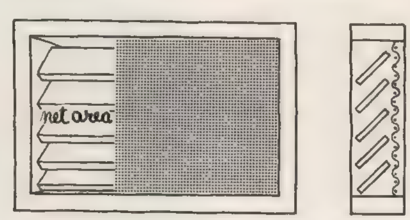
louvers plus 1/4" mesh cloth

gross area = 2 times net area



louvers plus 1/8" mesh

gross area = 2 1/4 times net area



louvers plus 1/16" mesh insect screen

gross area = 3 times net area

Ventilation: *Air-cooled walls and roofs (continued)*

Attic fans, employed to cool the house at night, are also effective when used during the day to cool the attic or loft space. Another solution is to cool the roof surface with water sprays—an effective, though often expensive, method.

Of course, the insulating value of these outer shells—really nothing more than an umbrella and raincoat for the building—is lost in winter. But their contribution is usually slight at best, and a modest increase in the amount of insulation that is employed in the body of the structure will more than compensate for them.

Experience shows that in summer an insulated attic that is not ventilated offers little comfort advantage over the same attic without insulation.

Therefore it is a good rule that *insulated attics or lofts should always be permanently vented* to conform at least to the minimum recommendations of the FHA. These are based on ventilation required to prevent condensation; they are not adequate to assure extra summer comfort.

The secondary value of air-cooled walls and roofs —their ability to release vapor that might penetrate the structural materials in winter—requires that the minimum vent openings remain free to operate all of the year. These must be designed to prevent high winds from driving snow and rain into the spaces. Vent openings that are made larger than the minimum—to provide greater summer comfort—may have shutters that reduce their area in winter to that required for vapor release.

Air-cooled walls require thoughtful design. If the vertical channels are narrow and air movement slow, they may fill with hoar frost in cold weather if an excessive amount of vapor reaches them. A vapor barrier of reasonable effectiveness should be used in air-cooled walls wherever practical.

Sidewall louvers at the loft level are made an inconspicuous part of the architectural design. Air movement is augmented by roof ventilators, and where necessary, by mechanical fans or blowers. Much larger ventilating capacity would provide greater comfort during summer.

Gable-end louvers, large enough to provide free air movement in the attic, work wonders for summer comfort. In this house, a large-capacity attic fan was arranged for night air-cooling of the house, plus daytime boosting of attic ventilation.

Continuous eave vents, supplemented by ridge vents, are the solution for hip-roofed buildings. Eave vents are easily incorporated in the design of the soffit. Similar eave venting is also desirable with louvers near peaks of gabled roofs to assure general air movement.

EWING GALLOWAY, N. Y.

Ventilation:

Designing for Summer comfort in hot, sunny climates

A special condition in design applies in the sunny, hot areas of the southwest and central or southern California. Here the earlier settlers found comfort, of a sort, within thick adobe or masonry walls. They used the physical principle that it takes a long time for heat to penetrate massive structures, plus the fact that cool night air would offset the delayed radiation of the sun heat into the interior long into the night.

This principle of "heat capacity" and its time lag is still good, but expensive to apply with present building costs. Another that works even better is a light-weight wall or roof (particularly for sunny east and west walls), thoroughly insulated with low-density material. This construction has low heat capacity (that is, it does not absorb and hold a lot of heat) plus high resistance to heat penetration.

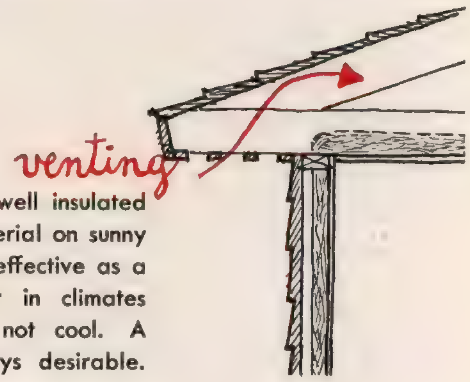
Other methods are to use the air-cooled walls just described, or to provide tree shade, or even vines on trellises standing free of the building. The air-cooled wall is the most practical solution for large or tall buildings that cannot be otherwise shaded. The tree and vine shade may well serve one story or even two-story dwellings or other small buildings.

four ways to achieve comfort in hot, sunny climates:

1

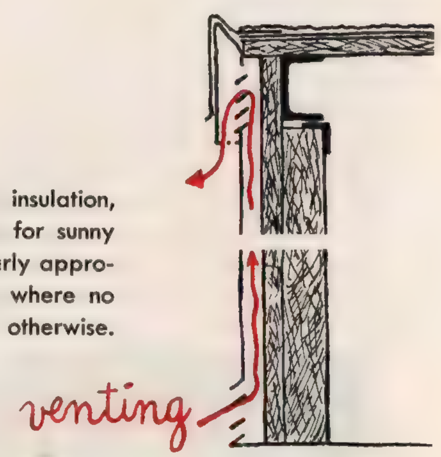
Thick-walled adobe buildings (*left*) were a logical native solution in the southwest because the material was cheap and available, and the high heat storage capacity of the heavy walls delayed heating the interior until cool night air arrived to offset indoor discomfort by ventilation.

2



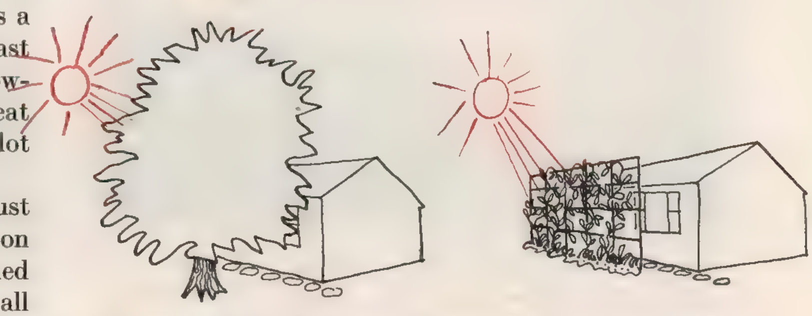
A light-weight wall, well insulated with low density material on sunny exposures, is just as effective as a massive wall, better in climates where night air is not cool. A vented attic is always desirable.

3



An air-cooled wall, plus insulation, is another good solution for sunny exposures. It is particularly appropriate for tall buildings where no shade can be obtained otherwise.

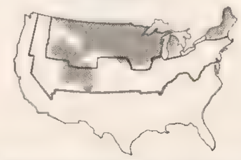
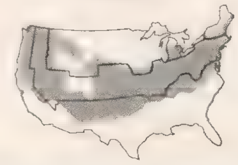
4



Tree shade or trellises with vines near the east and west walls, combined with an adequately air-cooled roof, will diminish the impact of sun heat in low and small buildings.

PART 2: Practice

Recommended design standards

PART OF BUILDING	ZONE I	ZONE II	ZONE III
			

Heat Control: Recommended Heat Transmission Rates (U) for Buildings

	Zone I Best	Zone I Good	Zone I Min.	Zone II Best	Zone II Good	Zone II Min.	Zone III Best	Zone III Good	Zone III Min.
ROOFS, and CEILINGS under vented lofts or attics	.06	.08	.12	.06	.08	.12	.06	.08	.15
WALLS- West	.06	.09	.13	.07	.10	.17	.07	.13	.20
East	.06	.09	.13	.07	.10	.17	.07	.13	.20
North	.06	.09	.13	.07	.11	.17	.09	.17	No Insul.
South	.06	.13	.15	.07	.13	.20	.13	.20	" "
FLOORS–Over vented, unheated spaces	.06	.09	.13	.07	.11	.17	.08	.17	" "
–Concrete slabs on ground*	.13 (C)	.25 (C)	.33 (C)	.13 (C)	.25 (C)	.50 (C)	.25 (C)	.33 (C)	.50 (C)

*Expressed as Conductance (C) of insulation installed between edge of floor slab and masonry foundation

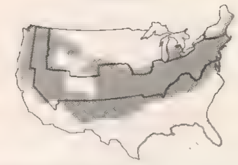
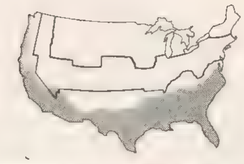
Vapor Control: Recommended Use of Vapor Barriers and Vapor Venting

	Zone I	Zone II	Zone III
ROOFS–Flat—under 5000 sq. ft.	Vents—1 sq. ft. net free area to 300 sq. ft. insulated area (1:300) with vents distributed uniformly at eaves or loft walls, plus vapor barrier, all zones		
–Flat—over 5000 sq. ft.	Vents—1:150 sq. ft. total, consisting of eave or loft wall vents 1:300, plus roof vents 1:300, located to assure uniform venting of loft		Same as for small area roofs with roof vents where needed
–Gable (no occupancy)	Vents—1:300 sq. ft. in at least two gable louvers near ridge, plus vapor barrier for all occupancies	Same vents as Zone I Vapor barrier required with high- and medium-moisture occupancies, optional with low	Same vents as Zone I No vapor barrier required except with high - moisture occupancies
–Hip (no occupancy)	Vents—1:300 sq. ft. total, with 1:600 uniformly distributed at eaves; 1:600 at ridge; all spaces inter-connected; plus vapor barriers with all occupancies	Same vents as Zone I Vapor barrier required with high - and medium - moisture occupancies, optional with low.	Same vents as Zone I No vapor barrier required except with high - moisture occupancies
–Gable or Hip (with attic occupancy anticipated)	Vents—1:300 sq. ft. total; with 1:600 uniformly distributed at eaves; 1:600 at ridge or gable ends, all spaces interconnected; plus vapor barrier in all zones and occupancies.		
WALLS–All Types	Vapor barrier required for all occupancies if U value of wall is less than 0.25 Btu, or if any exterior materials have a vapor permeability of less than 5 perms. Preferred in all walls.		Same as Zones I and II for high-moisture occupancies; no vapor barrier required in others.
CRAWL SPACES	Provide foundation vents totalling 2 sq. ft. net area per 100 lin. ft. of foundation perimeter plus ⅓ of 1 per cent of crawl space ground area. If ground cover is used, provide at least 10 per cent of above ventilation.		Substantially free sweep of air preferred.

Ventilation: Recommended Structural Ventilation for Summer Comfort

	Zones I and II	Zone III
LOFTS and ATTICS with insulated ceilings	Double the vent areas recommended for vapor venting (i.e., 1:300 becomes 1:150) and use "best" insulation practice.	Triple the vent areas for vapor venting.
WALLS, East and West	Sun-exposed walls of large area should have vertical, continuously-vented air space near outer skin to remove most of solar heat load, plus "best" insulation practice.	
NIGHT AIR COOLING	Attic or loft fans or blowers are desirable to cool interior of buildings not equipped with air conditioning for summer comfort. Follow industry standards for fan capacity. Minimum vents 1:100.	

Recommended design standards

PART OF BUILDING	ZONE I 			ZONE II 			ZONE III 		

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WALLS- West	.06	.09	.13	.07	.10	.17	.07	.13	.20
East	.06	.09	.13	.07	.10	.17	.07	.13	.20
North	.06	.09	.13	.07	.11	.17	.09	.17	No Insul.
South	.06	.13	.15	.07	.13	.20	.13	.20	" "
FLOORS–Over vented, unheated spaces	.06	.09	.13	.07	.11	.17	.08	.17	" "
–Concrete slabs on ground*	.13 (C)	.25 (C)	.33 (C)	.13 (C)	.25 (C)	.50 (C)	.25 (C)	.33 (C)	.50 (C)

*Expressed as Conductance (C) of insulation installed between edge of floor slab and masonry foundation

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–Flat—over 5000 sq. ft.	Vents—1:150 sq. ft. total, consisting of eave or loft wall vents 1:300, plus roof vents 1:300, located to assure uniform venting of loft		Same as for small area roofs with roof vents where needed
–Gable (no occupancy)	Vents—1:300 sq. ft. in at least two gable louvers near ridge, plus vapor barrier for all occupancies	Same vents as Zone I Vapor barrier required with high- and medium-moisture occupancies, optional with low	Same vents as Zone I No vapor barrier required except with high-moisture occupancies
–Hip (no occupancy)	Vents—1:300 sq. ft. total, with 1:600 uniformly distributed at eaves; 1:600 at ridge; all spaces inter-connected; plus vapor barriers with all occupancies	Same vents as Zone I Vapor barrier required with high- and medium-moisture occupancies, optional with low.	Same vents as Zone I No vapor barrier required except with high-moisture occupancies
–Gable or Hip (with attic occupancy anticipated)	Vents—1:300 sq. ft. total; with 1:600 uniformly distributed at eaves; 1:600 at ridge or gable ends, all spaces interconnected; plus vapor barrier in all zones and occupancies.		
WALLS–All Types	Vapor barrier required for all occupancies if U value of wall is less than 0.25 Btu, or if any exterior materials have a vapor permeability of less than 5 perms. Preferred in all walls.		Same as Zones I and II for high-moisture occupancies; no vapor barrier required in others.
CRAWL SPACES	Provide foundation vents totalling 2 sq. ft. net area per 100 lin. ft. of foundation perimeter plus ⅓ of 1 per cent of crawl space ground area. If ground cover is used, provide at least 10 per cent of above ventilation.		Substantially free sweep of air preferred.

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WALLS, East and West	Sun-exposed walls of large area should have vertical, continuously-vented air space near outer skin to remove most of solar heat load, plus "best" insulation practice.		
NIGHT AIR COOLING	Attic or loft fans or blowers are desirable to cool interior of buildings not equipped with air conditioning for summer comfort. Follow industry standards for fan capacity. Minimum vents 1:100.		

How to use "time-saver" design tables

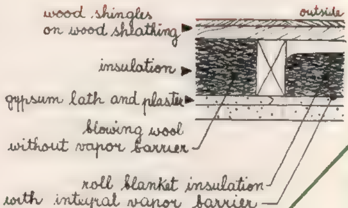
When you are designing a building you have certain conditions to meet. You have a reasonably wide choice of construction materials. You have cost limitations. Your building is located in a specific climate, on a specific site, with known exposures to sun and winds. It is intended for a specific occupancy, or else for rental to a wide variety of occupancies. You have reasonably definite standards of comfort to achieve, and your local fuel costs for heating, or power costs for comfort cooling, must be kept in mind as part of the ultimate operating costs for the building.

Functional design implies that you will select the type of construction that most completely satisfies all of these practical requirements. To a careful designer this means a laborious calculation of relative construction costs versus operating costs, and careful studies of the comfort and vapor control characteristics of each of the roof, wall and floor assemblies.

Except for relative construction costs, all of these questions can be quickly answered by examining the time-saver tables found in the next 34 pages.

Let's take a representative table apart to see how it can help you.

WALLS: wood frame
wood shingles on wood sheating



INSULATION THICKNESS, Inches		none	1	2	3	3⅝
CONDUCTANCE "C"			0.27	0.14	0.090	0.075
ALL ZONES						
HEAT TRANSMISSION "U"		0.25	0.13	0.087	0.066	0.061
% OF HEAT STOPPED by Insulation			48%	65%	73%	76%
ZONE I						
COMFORT RATING	winter	56.5°	63.0°	65.2°	66.4°	66.7°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$25.50	$34.50	$39.30	$40.20
OCCUPANCY-MOISTURE RATING		19%*	67%	76%	82%	**
ZONE II						
COMFORT RATING	winter	59.5°	64.5°	66.3°	67.2°	67.4°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$17.00	$23.00	$26.20	$26.80
OCCUPANCY-MOISTURE RATING		29%*	74%	81%	85%	**
ZONE III						
COMFORT RATING	winter	61.0°	65.3°	66.8°	67.6°	67.8°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$8.50	$11.50	$13.10	$13.40
OCCUPANCY-MOISTURE RATING		35%*	77%	83%	87%	**

*With no insulation and no vapor barrier, rating is based on dew-point temperature at inner face of sheeting.

**See notes on Blown Insulation, page 88.

IDENTIFICATION OF CONSTRUCTION

Each time-saver table relates to a specific construction that is identified first by the page heading and sub-heads and second by a sketch showing the materials employed in the assembly.

Where the assembly may use various thicknesses of a critical structural material, such as a concrete slab 3″ or 6″ thick, these variations are identified by headings or letter indexes over appropriate sections of the table, or separate tables.

INSULATION THICKNESS and CONDUCTANCE—"C"

INSULATION THICKNESS, Inches	none	1	2	
CONDUCTANCE "C"		0.27	0.14	0.

At the top of each table are column identifications. The first line lists the various thicknesses of a commercially available insulation appropriate to the section illustrated, but the first column always gives data for the construction without any insulation.

The second line gives the thermal conductance "C" of the insulation. This is the rate of heat flow through the material and is more completely defined on page 104. Not all insulations have the same conductance for the indicated thickness, but you can use the conductance value as your guide and then use a thickness of the insulation you have chosen that will match the conductance given in the table.

For example, in the sample table on the opposite page, the conductance "C" for 1 inch of insulation is shown as 0.27 Btu. If the insulation you propose to use has a heat transmission of 0.33 Btu for a one inch thickness you should use .33/.27 inches or about 1¼ inches to get the same values shown in the rest of the table.

HEAT TRANSMISSION—"U" and % OF HEAT STOPPED by insulation

HEAT TRANSMISSION "U"	0.25	0.13	0.087	0.
% OF HEAT STOPPED by Insulation		48%	65%	7

This band applies to all climatic zones. The top line shows the rate of heat transfer "U" through the entire section, in Btu per hour, per square foot, for each degree F difference between the outdoor and the indoor air adjacent to the construction.

This value is constantly used in all heating and air conditioning calculations and offers a direct comparison of thermal properties of different construction sections. Low values mean low heat transmission, hence superior performance.

The second line dramatizes the amount of heat stopped by the different thicknesses of insulation. It is a quick indication of the effectiveness of the insulation used.

CLIMATE ZONES

The remaining three sections of the table have color identifications to help you keep your comparative studies within the same climate zone (defined on page 14). Zone I with a pale blue-green tint is the Northern cold zone; Zone II in white is the middle band of moderate climate; Zone III with the warm tint is the southern and Pacific Coast warm zone. Once you have located your project in one of these zones, you should make all comparisons within the same color band.

To make the further calculations required for each zone, certain averages had to be assumed. Here they are for reference purposes:

	Design Temp.	Degree Days
Zone I—Cold	−20°	9000
Zone II—Moderate	0°	6000
Zone III—Warm	+10°	3000

These two sets of values, "design temperature" and "degree days" were explained on page 14 and the latter is again defined on page 104.

COMFORT RATING—WINTER

COMFORT RATING	winter	56.5°	63.0°	65.2°	6(

The comfort yardstick described on page 16 explains the value of this rating. The figures given are the temperatures which the interior surface of the section (ceiling, wall, or floor) will attain when the interior is kept at 70° and the outdoor temperature is at the design temperature assumed for each zone.

The winter rating indicates the degree of comfort that is contributed by different amounts of insulation. The colder the surface, the greater the heat loss is from the body. A rating approaching 70° indicates maximum comfort. A rating below 58° indicates a perceptible degree of discomfort.

COMFORT RATING—SUMMER

COMFORT RATING	summer	86.2°	80.8°	79.0°	78

The summer comfort rating works on the same principle as the winter rating, but in reverse. It assumes that the indoor air is 75° and the combined

effect of sun and air heat will bring the outside surfaces to a temperature of 150° F.

Since we do not want the enclosing surfaces to radiate heat to our bodies in summer, the figures nearest to 75° represent maximum comfort.

By comparing the summer and winter comfort ratings of different constructions you can immediately determine which construction will be capable of providing the greatest indoor comfort when the building is properly heated or cooled.

ECONOMY RATING

ECONOMY RATING		$25.50	$34.50	$3

This rating, based on the length and severity of the heating season, tells you on a comparative basis, the dollar value of the fuel you can *save* annually per 1000 square feet of insulated area. This varies with the thickness and effectiveness of the insulation indicated at the top of each column.

For comparative studies of different sections you need no further facts. In each table the dollar savings is based on the heat that would be lost if no insulation were used.

You can also make a rough comparison of these figures with the cost of the insulation you propose to use. In the example illustrated, a 3-inch thickness of insulation saves $39.30 annually for each 1000 sq. ft. of the wall shown. If the insulation you select will cost 15 cents per square foot installed, or $150 per 1000 sq. ft., you will save this cost in less than four heating seasons.

If you wish to make direct calculations of fuel savings in a building from these figures, you should adjust them for your local "degree days" and "cost of fuel per therm" by the calculation methods given on page 110. (For reference, the fuel cost used is 10 cents per *effective therm.*)

OCCUPANCY-MOISTURE RATING

OCCUPANCY-MOISTURE RATING	19%*	67%	76%	8

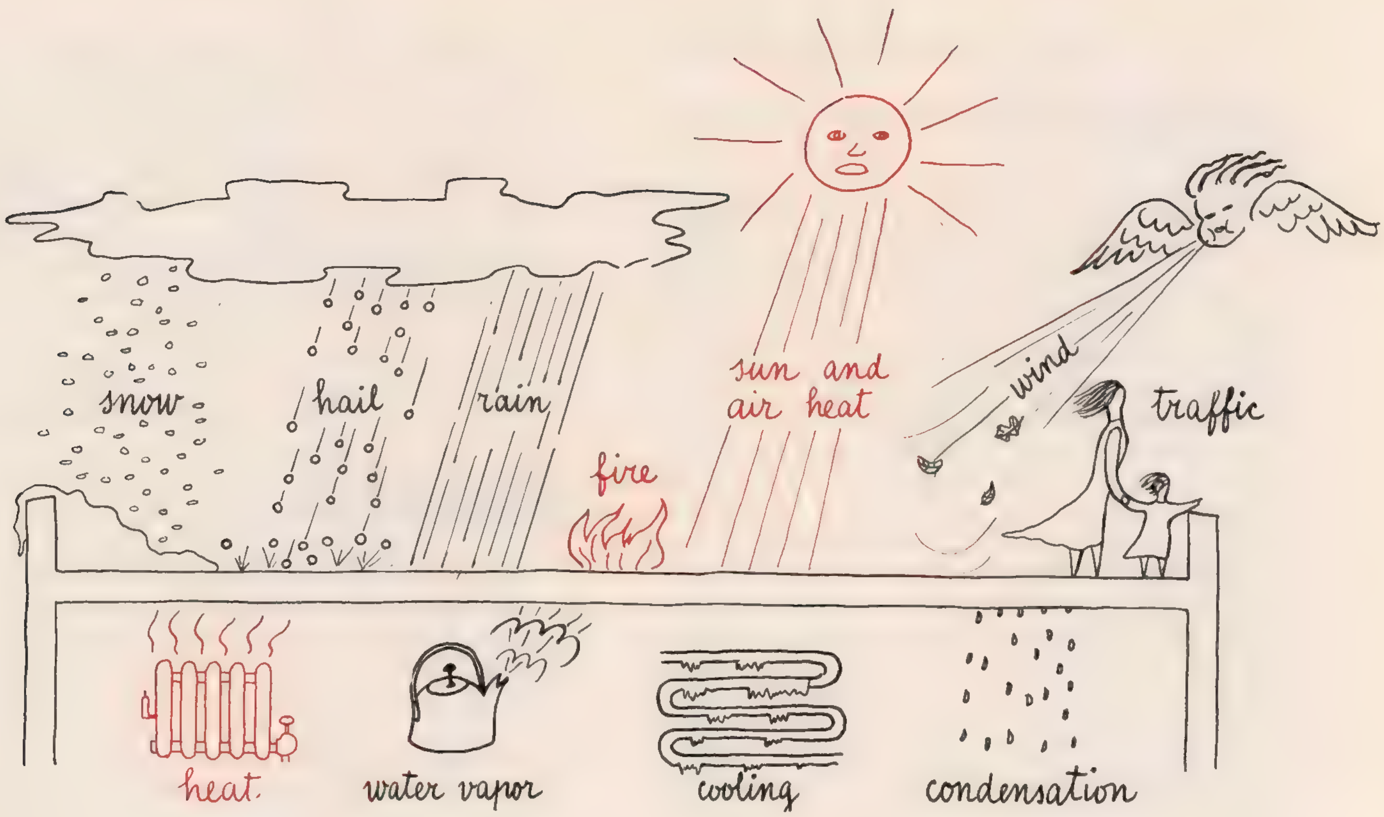
This rating tells you whether or not the construction illustrated will be safe from winter condensation when the moisture level generated by the proposed occupancy of the building is known. (Usually the latter can be established from the data on page 39). The rating gives the highest permissible relative humidity that can be maintained steadily within the building during periods when the outdoor temperature is at the design temperature assumed for the zone, without danger that condensation will begin to accumulate within the structural section or on its exposed surface.

In the sample table the wood frame wall, in Zone I, without insulation, can tolerate only 19% relative humidity before condensation is likely to develop, assuming no vapor barrier is installed. This is hardly satisfactory for even normal residential occupancies, particularly if the outside design temperature prevails for any extended period of time. But the same construction in Zones II or III will tolerate 29% and 35% relative humidities respectively, which are nearer the levels likely to prevail. If insulation of any thickness, *with a warm side vapor barrier*, is installed in the construction the relative humidity can be 67% or higher, which is far above the level that is customarily found in dwellings.

For the reasons given in the discussion of the time element on page 48, judgment must be exercised in the use of these ratings in marginal cases.

When no vapor barrier is installed where one is called for in the construction sketches, these ratings must be disregarded. To determine whether a construction will perform satisfactorily without a vapor barrier for any given occupancy, a study should be made by methods given on page 113 of the relative vapor permeabilities of the materials used.

Design of Insulated Roofs or Ceilings



Design of Insulated Roofs or Ceilings

Roofs take severe punishment from the climate in all parts of the United States. Sun heat may reach 150° on flat roofs anywhere in the country, even higher temperatures (165° or more) for sloping roofs that are normal to the sun angle. High winds have no special home; they too, can range up to a full gale anywhere and may become tornadoes or cyclones in most sections, even though these extremes are rare.

Snow, sleet and hail make Zones I and II particularly tough on all roofs; they occur also in Zone III but with less frequency. Rain is the major force that roofs must protect against in all but the arid regions of the southwest, and even there the occasional rains may cause trouble if the excessive sun exposure has deteriorated the roofing material.

Some roofs are even subject to traffic loads; as sun decks and "promenades."

Below the deck are man-made forces working outwardly. Winter heat seeks to escape. Summer comfort cooling, costing several times as much as heating, must be contained. And the water vapor in the air in winter must be kept from condensing within the roof structure and causing indoor rainfall.

For all these reasons, roof design deserves more attention than it usually receives. Roof insulation, vapor control and both heat and vapor ventilation are just as important to good performance as the creation of a water tight, or water shedding, surface.

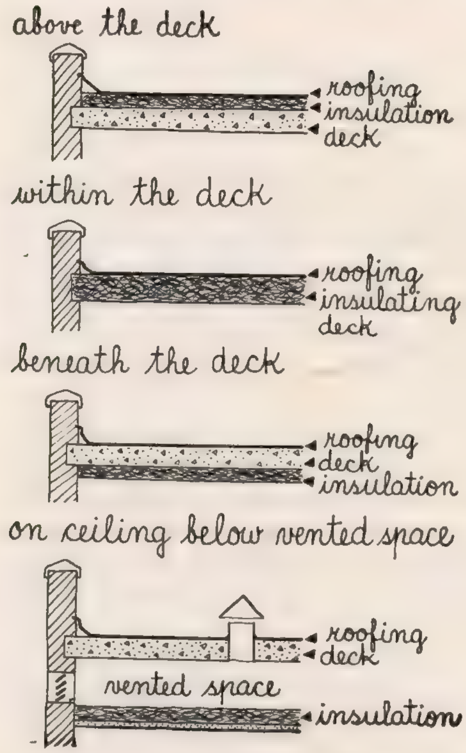
Roofs can be insulated in four ways: (1) Above the structural deck; (2) by the use of insulating materials to form the deck itself; (3) immediately beneath the structural deck; and (4) on a ceiling below the roof proper, with a loft or attic between this ceiling and the deck. Each method involves special problems of its own, which will be discussed in later pages.

In existing buildings the choice of location may be limited by structural conditions more than by economic or performance factors.

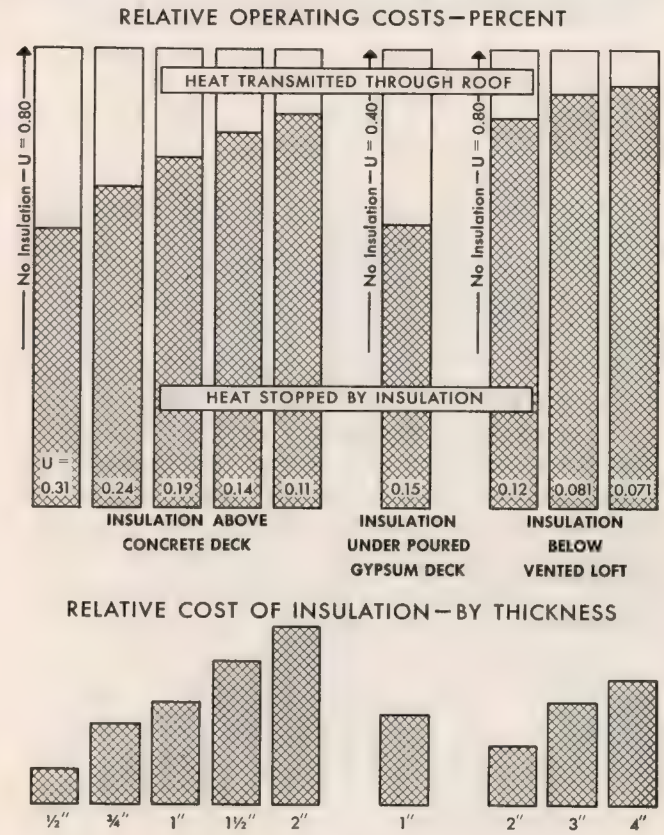
In the design of new structures, where arbitrary predilections for one type of roof or another can be set aside, there are many opportunities to design roofs particularly adapted to both the local climate and the anticipated occupancy of the building.

For example: the accompanying relative cost chart indicates that if your problem is one of lowest initial cost for insulation and lowest operating cost for heating or cooling, both (expressed as fuel savings) can be attained better with an insulated ceiling below ventilated loft or attic space than with insulation either above, in, or immediately below the deck. This design also has comfort advantages and can be designed to handle very high moisture occupancies.

FOUR WAYS TO INSULATE A ROOF



ECONOMICS OF ROOF INSULATION



If your problem involves high indoor moisture, there are some roof designs that are entirely unsuitable.

If your problem requires a roof that serves as the interior ceiling as well, your choice of insulating above or within or below the deck is largely a matter of occupancy-moisture rating, plus internal appearance, plus relative costs.

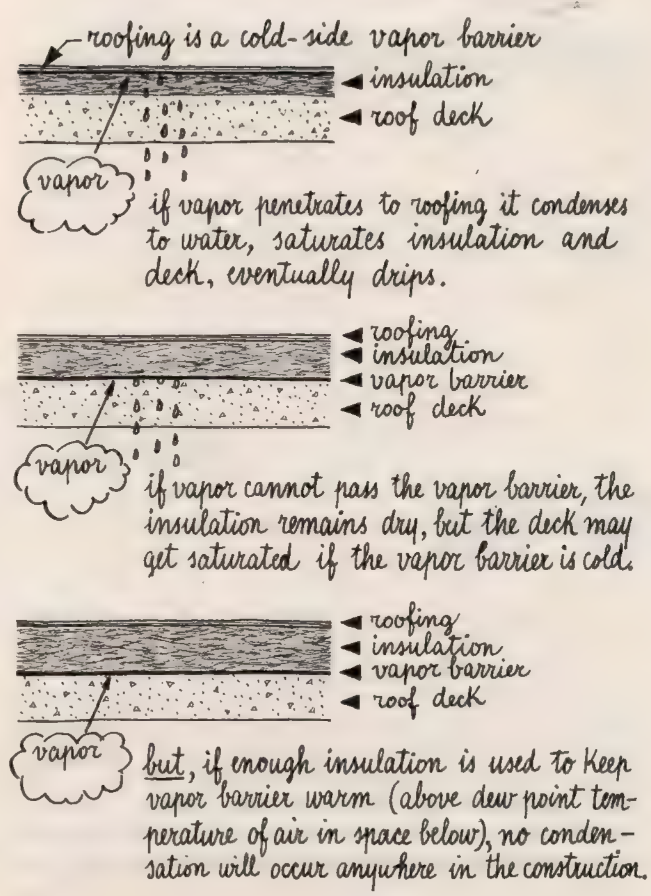
Again, if your roof must carry traffic loads, your choice is between load-bearing insulations above the deck, in thicknesses adequate to compensate for their relatively high conductance, or the use of more efficient, non-load bearing insulations below the deck or on the ceiling forming a loft space.

In all cases, careful attention should be given to vapor barriers and their location, or to vapor control by ventilation, wherever the moisture level generated by the occupancy during periods of cold weather indicates a potential condensation problem.

All of these problems can be solved without tedious calculations by studying the thermal properties of the roofs shown in the following pages.

If this study is made during the preliminary design stage, you can design around the type of roof construction that will give the best performance, at the least initial and operating costs, for the occupancy and climate you are dealing with.

BASIC VAPOR CONTROL DETAILS



ROOFS: insulated above the deck

Many built-up roofing jobs on flat or low-slope roofs have been blamed for leaking when the real cause of internal dripping has been condensation.

The roofing itself (by roofing we mean the water-tight membrane or water-shedding material) is the hottest part of the roof during sunny hours, and the coldest part in winter, particularly at night.

If water vapor can penetrate the roof structure in winter from within the building it will condense on the underside of the cold roofing. This is inevitable unless *no* moisture has been added to the air in the building; that is, unless the vapor pressures, indoors and out, are equal. If the deck material, or any insulation between the deck and the roofing, is absorptive of moisture, no dripping will occur until these materials are fully saturated. Otherwise, dampness and dripping will appear soon after the right temperature conditions are reached.

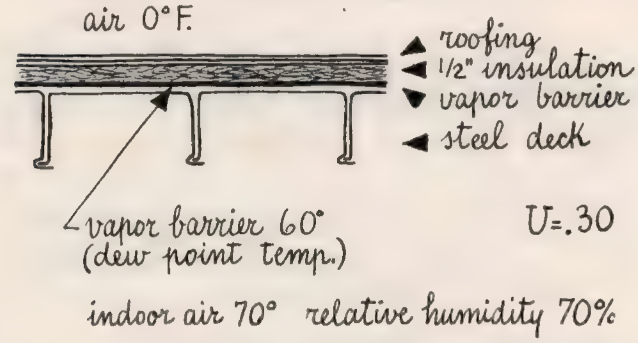
VAPOR CONTROL

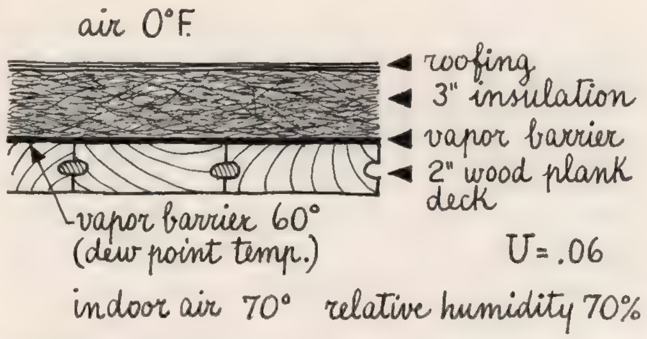
To offset this, a vapor barrier may be used, installed as near as may be practicable to the warm side of the construction. In most cases where insulation is installed above the deck, the only workable surface that can be made water-tight is the top side of the deck.

Condensation can be completely forestalled if this vapor barrier is maintained at a temperature above the dew point of the indoor air.

Here is where a surprising thing occurs. If the deck construction is a poor insulator, the amount of insulation needed to keep the vapor barrier warm is not so great as the amount required when the deck is itself a fairly good insulator. (See diagram.) This is quite independent of the overall heat resistance of the roof. The use of sufficient insulation to prevent condensation is particularly important over decks which can be weakened by protracted dampness, such as wood or gypsum.

A vapor barrier is therefore needed much more frequently than is generally supposed. Even insulating materials that are not porous to vapor may require them because if vapor passes up through the joints between the blocks or boards, it can condense, freeze and form ice ridges under the roofing. Condensation, resulting from the lack of a good vapor barrier, probably causes more trouble than leaks do.





Two roof designs having the same temperature at the vapor barrier (to prevent condensation) require different thicknesses of insulation. The wood deck, being a better insulation in itself, requires the greater insulation thickness, even though the U value falls far below what is otherwise required.

* * *

"BLISTERS" MEAN TIGHT CONSTRUCTION

Most roof insulating materials are largely air entrapped by cells or fibers. The air content may range from 50% to 95% of the mass. Those with the highest percentage of air are the best insulators for a given thickness.

What happens to all this air when the sun hits the roof and raises its temperature 100° F. or so above the night-time cold? The air will expand, if it can.

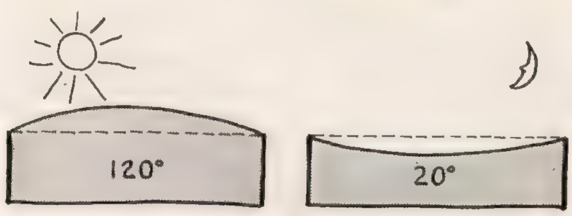
If air is confined at, say 20° F., and its temperature raised 100° F., it will generate a pressure of approximately 450 lbs. per square foot, equal to a mass of concrete one foot square and three feet high!

When the air is held within strong-walled cells, as in cellular glass, this expansion is not important. But when the air is free to move, as in most other materials, it can make this pressure be felt.

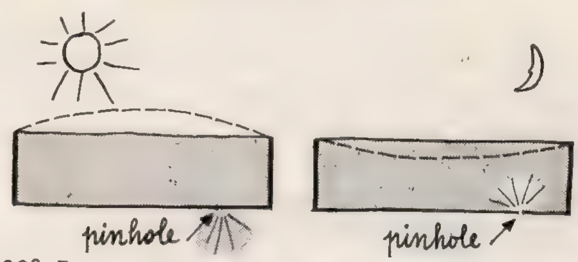
Now suppose a porous insulation is confined between the tight, multi-layer roofing above and a tight vapor barrier below, with all edges hermetically sealed. When the sun heat expands the air either of two things will happen: (1) The pressure may bulge and "blister" the roofing, and perhaps separate it from the insulation, or (2) the pressure will blow pin holes through whichever enclosing surface has the weakest spots, and thus relieve the pressure caused by expansion.

At night, the reverse happens. The air in the insulation cools and contracts. It draws the roofing down tight (if it is free to move at all) and then begins to draw in air through the same pin holes that the high pressure has formed. If these pin holes are in the roofing, water can be drawn in; if they are in the vapor barrier, moisture-laden air can enter from within the building.

In effect, the formation of blisters under the roofing is evidence of tight construction; when they do not form, there are holes somewhere through which the trapped air can breathe! Over a period of time, perhaps months or even years, this "breathing" action due to temperature changes can cause the insulation to become saturated from above or below. Wet insulation ceases to insulate and thus aggravates the problem. Organic insulations, if wet for long periods, may rot in time and fail completely.



If a rubber-topped box were sealed with air at 70° F. and then heated to 120° F., the top would bulge. If cooled to 20° F., it would become concave. This is essentially what happens to air entrapped in insulation when temperatures change and is a primary cause of roof blisters.



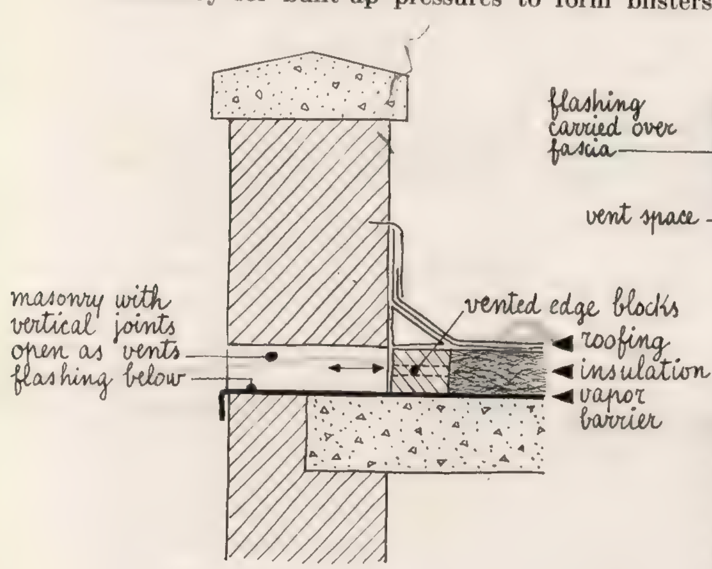
This 100° F. temperature change often occurs on roofs between daytime sun heat in winter (120° F.) and cold night air (20° F.). If the air can escape through any pin-hole when hot, it will do so. At night warm indoor air may be drawn in, often carrying moisture with it.

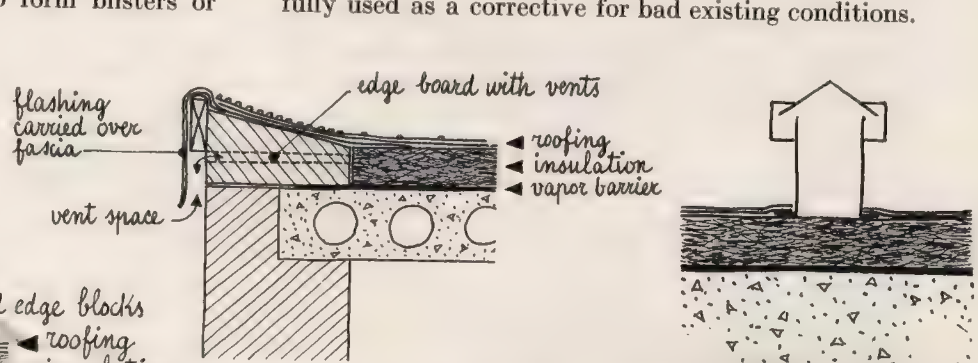
* * *

"BREATHING" VENTS FOR ROOF INSULATION

Two methods of preventing this condition have been developed. One, appropriate with vapor-porous roof insulations, is side venting as shown in the left and center diagrams below. Vents under metal copings, or through vertical joints left open in masonry walls, allow the insulation to breathe to the *outer air where the vapor pressure is lowest.* ("Cut-offs" should be located to permit side venting). Thus there is no tendency for built-up pressures to form blisters or to force pin holes in weak parts of the vapor barrier or roofing.

The other, at right, is to install "breather" ventilators to the outside air that penetrate the roofing between "cut-offs" and reach into the insulation itself. These vents are often an obstruction on the roof and require careful installation, lest they cause more leaks than they cure, but the method is successfully used as a corrective for bad existing conditions.





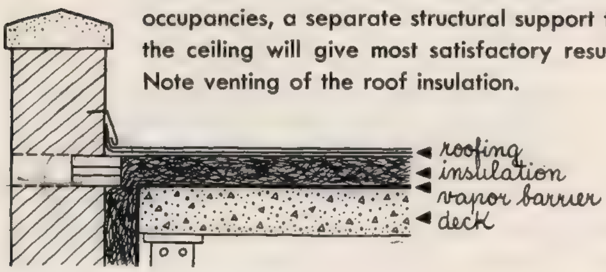
Two details (left and above) show a new method of relieving the pressure of air within a porous roof insulation. The edge blocks or boards are perforated and vented to the outer air. The insulation can then "breathe", and the hazards of condensation and blistering are reduced. The same effect can be obtained by roof vents of small size (above, right), penetrating the built-up roofing to the porous insulation within each "cut-off" area. Use only for correcting faulty conditions, as such vents may impede use of roof, or invite new leaks.

ROOFS: insulated above the deck (continued)

CONTINUOUS ROOF-WALL VAPOR BARRIERS

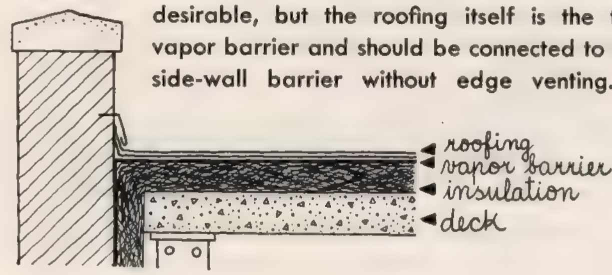
Structures having an excessively high moisture level indoors require highly effective, continuous, warm-side vapor barriers. Such conditions are found in textile mills; in the manufacture of decalcomanias and in other process industries requiring or creating high humidities. In low-temperature storage buildings such as freezers and lockers, the vapor barrier must be continuous on the outside of the insulation.

Where a building must have insulated walls and ceilings continuously vapor sealed on the warm (interior) side, as in high-moisture occupancies, a separate structural support for the ceiling will give most satisfactory results. Note venting of the roof insulation.



In both cases the problem is to maintain continuity of the vapor barrier at the junction of roofs and walls, and sometimes between walls and floors. The designer should anticipate this problem by special design at these junctures, not only to make the connection of the vapor barriers possible, but to allow a practical sequence of construction operations.

A cold storage building requires the vapor barrier on the outer side of the insulation. Again, an independently supported roof is desirable, but the roofing itself is the top vapor barrier and should be connected to the side-wall barrier without edge venting.



* * *

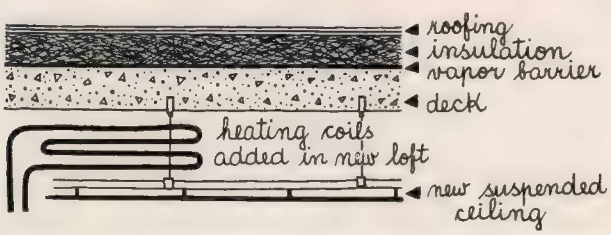
VAPOR CONTROL WITH SUSPENDED CEILINGS

Occasionally a high-humidity occupancy in a building insulated above the roof deck requires a suspended ceiling in certain areas, such as an acoustical ceiling over an office or where noisy machinery must be quieted. When this ceiling unbalances the original thermal design of the roof, it may introduce a condensation problem that did not exist before. This may happen when the ceiling acts as an insulator, thus lowering the temperature of the vapor barrier below the acceptable dew-point temperature.

There are three ways to meet this condition.

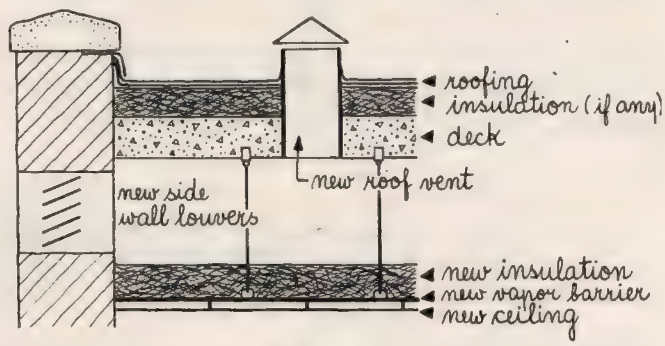
One is to introduce heat within the space formed between the suspended ceiling and the underside of the roof, solely to keep the vapor barrier above the required dew-point.

Another is to ventilate this space, mechanically or by side vents, and to insulate above the suspended ceiling so that the outer air will not cause excessive heat loss through the ceiling. Of course this method makes the original roof insulation of negligible value.

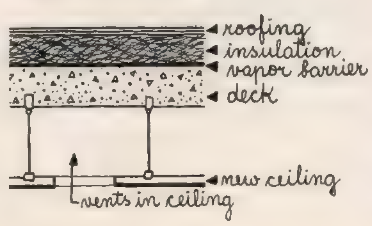


When a new suspended ceiling unbalances the original roof design by adding insulation value below the deck, heat may be added to forestall condensation.

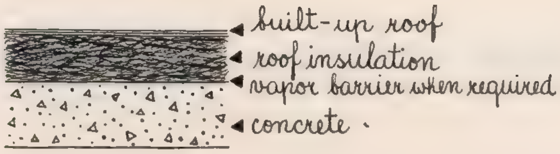
The third is to leave openings in the suspended ceilings so that room air may circulate under the roof at the actual room temperature for which the roof and its vapor barrier was designed. If this would create a dust or lint problem (as in textile mills) circulation can be secured by a blower working through air filters.



Sidewall and roof ventilators may be used to prevent condensation if the new ceiling is adequately insulated. A ceiling vapor barrier is indicated for buildings having high-moisture occupancies.



Original thermal balance can be maintained by providing enough vents in the new suspended ceiling to assure that the air in the new loft is as warm as before.



ROOFS: concrete deck

gravel concrete

2½" slab

INSULATION THICKNESS, Inches	none	½	¾	1	1¼	1½	2
CONDUCTANCE "C"		0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES							
HEAT TRANSMISSION "U"	0.86	0.32	0.24	0.19	0.16	0.14	0.11
% OF HEAT STOPPED by Insulation		63%	72%	78%	81%	84%	87%
ZONE I							
COMFORT RATING winter	30.4°	55.3°	59.0°	61.2°	62.6°	63.5°	64.9°
COMFORT RATING summer	116.8°	92.8°	88.9°	86.3°	84.6°	83.3°	81.5°
ECONOMY RATING		$118.20	$134.60	$144.50	$151.30	$156.20	$162.90
OCCUPANCY-MOISTURE RATING	11%	49%	58%	65%	71%	74%	79%
ZONE II							
COMFORT RATING winter	39.2°	58.5°	61.4°	63.2°	64.3°	65.0°	66.1°
COMFORT RATING summer	116.8°	92.8°	88.9°	86.3°	84.6°	83.3°	81.5°
ECONOMY RATING		$78.80	$89.70	$96.30	$100.90	$104.20	$108.60
OCCUPANCY-MOISTURE RATING	20%	57%	66%	72%	76%	79%	83%
ZONE III							
COMFORT RATING winter	43.5°	60.2°	62.6°	64.2°	65.1°	65.7°	66.6°
COMFORT RATING summer	116.8°	92.8°	88.9°	86.3°	84.6°	83.3°	81.5°
ECONOMY RATING		$39.40	$44.80	$48.10	$50.40	$52.00	$54.30
OCCUPANCY-MOISTURE RATING	26%	62%	70%	76%	79%	82%	85%

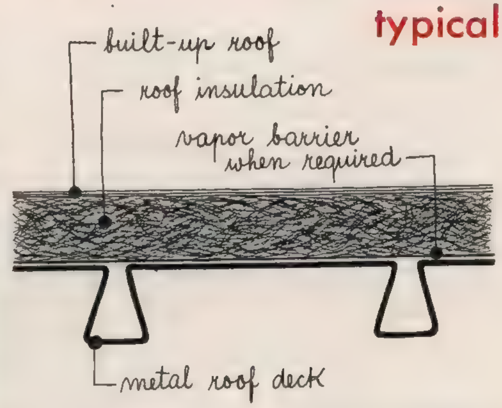
4" slab

INSULATION THICKNESS, Inches	none	½	¾	1	1¼	1½	2
CONDUCTANCE "C"		0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES							
HEAT TRANSMISSION "U"	0.78	0.31	0.23	0.19	0.16	0.14	0.11
% OF HEAT STOPPED by Insulation		60%	70%	76%	79%	82%	86%
ZONE I							
COMFORT RATING winter	34.0°	55.7°	59.4°	61.2°	62.6°	63.5°	64.9°
COMFORT RATING summer	113.8°	92.3°	88.5°	86.0°	84.4°	83.2°	81.5°
ECONOMY RATING		$101.90	$118.90	$127.50	$134.10	$138.30	$145.00
OCCUPANCY-MOISTURE RATING	8%	43%	54%	61%	65%	70%	75%
ZONE II							
COMFORT RATING winter	42.0°	58.9°	61.8°	63.2°	64.2°	65.0°	66.0°
COMFORT RATING summer	113.8°	92.3°	88.5°	86.0°	84.4°	83.2°	81.5°
ECONOMY RATING		$67.80	$79.30	$85.00	$89.40	$92.20	$96.60
OCCUPANCY-MOISTURE RATING	17%	53%	62%	68%	73%	75%	80%
ZONE III							
COMFORT RATING winter	46.0°	60.5°	62.9°	64.2°	65.1°	65.7°	66.6°
COMFORT RATING summer	113.8°	92.3°	88.5°	86.0°	84.4°	83.2°	81.5°
ECONOMY RATING		$33.90	$39.60	$42.50	$44.70	$46.10	$48.30
OCCUPANCY-MOISTURE RATING	23%	58%	67%	72%	76%	79%	82%

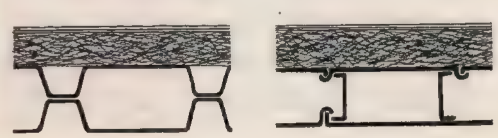
ROOFS: metal deck

typical

INSULATION THICKNESS, Inches	none	½	¾	1	1¼	1½	2
CONDUCTANCE "C"		0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES							
HEAT TRANSMISSION "U"	1.04	0.33	0.25	0.20	0.17	0.14	0.11
% OF HEAT STOPPED by Insulation		68%	76%	81%	84%	87%	89%
ZONE I							
COMFORT RATING winter	22.0°	54.8°	58.5°	60.8°	62.2°	63.5°	65.0°
COMFORT RATING summer	123.4°	93.5°	89.2°	86.5°	84.6°	83.4°	81.6°
ECONOMY RATING		$153.80	$170.80	$181.80	$188.30	$195.00	$201.30
OCCUPANCY-MOISTURE RATING	15%	58%	66%	73%	77%	80%	84%
ZONE II							
COMFORT RATING winter	32.6°	58.2°	61.0°	62.8°	63.9°	65.0°	66.1°
COMFORT RATING summer	123.4°	93.5°	89.2°	86.5°	84.6°	83.4°	81.6°
ECONOMY RATING		$102.50	$114.00	$121.20	$125.60	$130.00	$134.20
OCCUPANCY-MOISTURE RATING	25%	65%	74%	78%	81%	84%	87%
ZONE III							
COMFORT RATING winter	38.0°	59.9°	62.3°	63.9°	64.8°	65.7°	66.6°
COMFORT RATING summer	123.4°	93.5°	89.2°	86.5°	84.6°	83.4°	81.6°
ECONOMY RATING		$51.20	$57.00	$60.60	$62.80	$65.00	$67.10
OCCUPANCY-MOISTURE RATING	31%	71%	77%	81%	84%	86%	89%



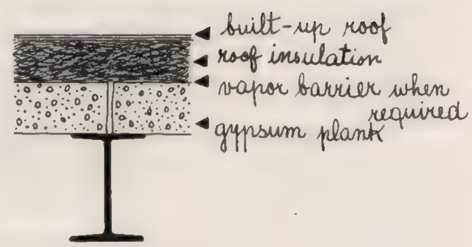
various types of steel decks assumed to have substantially same thermal value



ROOFS: precast plank deck

gypsum plank, 2″

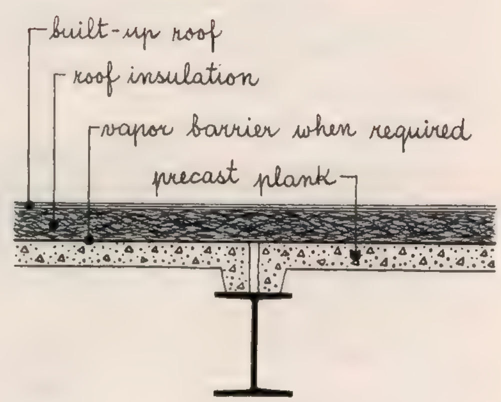
INSULATION THICKNESS, Inches		none	1/2	3/4	1	1 1/4	1 1/2	2
CONDUCTANCE "C"			0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES								
HEAT TRANSMISSION "U"		0.64	0.28	0.22	0.18	0.15	0.13	0.11
% OF HEAT STOPPED by Insulation			56%	66%	72%	76%	80%	84%
ZONE I								
COMFORT RATING	winter	40.5°	57.0°	59.9°	61.7°	62.9°	63.9°	65.2°
	summer	108.0°	91.0°	87.7°	85.5°	84.0°	82.9°	81.2°
ECONOMY RATING			$77.40	$90.90	$99.30	$105.30	$109.80	$115.50
OCCUPANCY-MOISTURE RATING		6%	36%	46%	53%	58%	63%	69%
ZONE II								
COMFORT RATING	winter	47.0°	59.9°	62.2°	63.5°	64.5°	65.3°	66.2°
	summer	108.0°	91.0°	87.7°	85.5°	84.0°	82.9°	81.2°
ECONOMY RATING			$51.60	$60.60	$66.20	$70.20	$73.20	$77.00
OCCUPANCY-MOISTURE RATING		14%	46%	55%	61%	65%	70%	75%
ZONE III								
COMFORT RATING	winter	50.3°	61.3°	63.3°	64.5°	65.3°	65.9°	66.8°
	summer	108.0°	91.0°	87.7°	85.5°	84.0°	82.9°	81.2°
ECONOMY RATING			$25.80	$30.30	$33.10	$35.10	$36.60	$38.50
OCCUPANCY-MOISTURE RATING		19%	51%	59%	65%	71%	74%	78%



*Heat transmission coefficients of plank vary with shape and manufacturer. Nominal conductivity, k=3.30, used in calculations.

gravel concrete plank, 1″

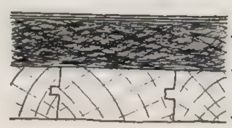
INSULATION THICKNESS, Inches		none	1/2	3/4	1	1 1/4	1 1/2	2
CONDUCTANCE "C"			0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES								
HEAT TRANSMISSION "U"		0.96	0.33	0.25	0.20	0.17	0.14	0.11
% OF HEAT STOPPED by Insulation			66%	74%	79%	83%	85%	88%
ZONE I								
COMFORT RATING	winter	25.7°	54.8°	58.6°	60.9°	62.4°	63.5°	64.9°
	summer	121.6°	93.5°	89.2°	86.6°	84.7°	83.4°	81.6°
ECONOMY RATING			$136.20	$154.00	$164.30	$172.00	$177.00	$183.20
OCCUPANCY-MOISTURE RATING		12%	53%	62%	69%	74%	77%	82%
ZONE II								
COMFORT RATING	winter	35.5°	58.2°	61.1°	62.9°	64.0°	64.9°	66.0°
	summer	121.6°	93.5°	89.2°	86.6°	84.7°	83.4°	81.6°
ECONOMY RATING			$90.80	$102.80	$109.90	$114.40	$118.00	$122.00
OCCUPANCY-MOISTURE RATING		22%	62%	68%	75%	79%	82%	85%
ZONE III								
COMFORT RATING	winter	40.4°	59.7°	62.4°	63.9°	64.9°	65.6°	66.6°
	summer	121.6°	93.5°	89.2°	86.6°	84.7°	83.4°	81.6°
ECONOMY RATING			$45.40	$51.30	$54.80	$57.20	$59.00	$61.10
OCCUPANCY-MOISTURE RATING		28%	66%	74%	78%	81%	84%	87%



ROOFS: wood deck
flat or low slope

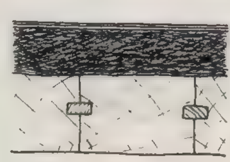
2″ plank

INSULATION THICKNESS, Inches		none	1/2	3/4	1	1 1/4	1 1/2	2
CONDUCTANCE "C"			0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES								
HEAT TRANSMISSION "U"		0.29	0.18	0.16	0.13	0.12	0.11	0.087
% OF HEAT STOPPED by Insulation			34%	46%	54%	59%	63%	70%
ZONE I								
COMFORT RATING	winter	56.7°	61.6°	62.8°	63.8°	64.6°	65.1°	66.0°
	summer	91.3°	85.7°	84.1°	82.9°	82.1°	81.3°	80.3°
ECONOMY RATING			$21.00	$28.90	$33.50	$37.00	$39.50	$43.70
OCCUPANCY-MOISTURE RATING		2%	14%	20%	26%	31%	35%	43%
ZONE II								
COMFORT RATING	winter	59.6°	63.4°	64.4°	65.2°	65.8°	66.2°	66.9°
	summer	91.3°	85.7°	84.1°	82.9°	82.1°	81.3°	80.3°
ECONOMY RATING			$14.00	$19.20	$22.30	$24.60	$26.30	$29.10
OCCUPANCY-MOISTURE RATING		7%	24%	30%	36%	41%	45%	52%
ZONE III								
COMFORT RATING	winter	61.1°	64.4°	65.2°	65.9°	66.4°	66.7°	67.3°
	summer	91.3°	85.7°	84.1°	82.9°	82.1°	81.3°	80.3°
ECONOMY RATING			$7.00	$9.60	$11.20	$12.30	$13.20	$14.60
OCCUPANCY-MOISTURE RATING		13%	30%	36%	42%	46%	50%	57%



3″ plank

INSULATION THICKNESS, Inches		none	1/2	3/4	1	1 1/4	1 1/2	2
CONDUCTANCE "C"			0.50	0.33	0.25	0.20	0.17	0.13
ALL ZONES								
HEAT TRANSMISSION "U"		0.21	0.15	0.13	0.12	0.10	0.093	0.079
% OF HEAT STOPPED by Insulation			30%	39%	46%	52%	56%	63%
ZONE I								
COMFORT RATING	winter	60.2°	63.1°	64.0°	64.7°	65.2°	65.7°	66.4°
	summer	87.3°	83.8°	82.7°	81.9°	81.2°	80.6°	79.8°
ECONOMY RATING			$13.50	$17.70	$21.00	$23.70	$25.50	$28.80
OCCUPANCY-MOISTURE RATING		2%	9%	14%	18%	23%	27%	33%
ZONE II								
COMFORT RATING	winter	62.2°	64.5°	65.2°	65.8°	66.2°	66.7°	67.2°
	summer	87.3°	83.8°	82.7°	81.9°	81.2°	80.6°	79.8°
ECONOMY RATING			$9.00	$11.80	$14.00	$15.80	$17.00	$19.20
OCCUPANCY-MOISTURE RATING		6%	18%	24%	28%	33%	37%	43%
ZONE III								
COMFORT RATING	winter	63.5°	65.4°	66.0°	66.5°	66.8°	67.1°	67.6°
	summer	87.3°	83.8°	82.7°	81.9°	81.2°	80.6°	79.8°
ECONOMY RATING			$4.50	$5.90	$7.00	$7.90	$8.50	$9.60
OCCUPANCY-MOISTURE RATING		10%	24%	30%	34%	39%	43%	49%



ROOFS: wood deck, with exposed rafters

JULIUS SHULMAN

"Ranch" style ceilings with exposed rafters and roof planking can be protected for summer comfort and winter economy by installing insulation above the deck. Detail from work of Smith & Williams, architects.

RODNEY MC CAY MORGAN

Popular with architects of modern "ranch" style, one story houses, is the return to bare rafters, or trusses and purlins, supporting a low-slope plank roof. When used in dry climates, the principal problem is adequate protection from sun heat; when employed in Zone I, or even in Zone II, the prevention of condensation is equally important.

Two basic designs are involved.

One method, opposite, exposes the roof planking on the ceiling side. Insulation is placed above the deck. A vapor barrier on the deck is highly desirable, for experience has shown that even in the San Francisco Bay area, occasional periods of rainy weather have actually caused serious condensation in roofs of this type where no vapor barrier was used on the under side of the insulation. If the roofing is of shingles or shakes they may be attached to shingle lath installed over the insulation, with the latter protected on the upper side only by a lapped layer of Slater's felt or other vapor-porous roofing paper. When the roofing is a built-up type, venting of the insulation at the eaves may be desirable, as suggested on page 71.

Another method, below, places insulation against the under side of the plank deck, between the rafters or trusses, primarily to gain the acoustical value of the insulating material. In this design no warm side barrier is feasible. When the roofing is of shakes or shingles over a vapor-porous roofing felt, the construction may tolerate considerable internal moisture for brief periods, or moderate moisture for longer periods, without showing condensation, because the whole construction is then relatively permeable to vapor. But if a multi-ply bitumen roofing is used, it constitutes a cold side vapor barrier, and when condensing conditions prevail the only thing that will retard or prevent dripping is the moisture-holding capacity of the roof decking and insulation.

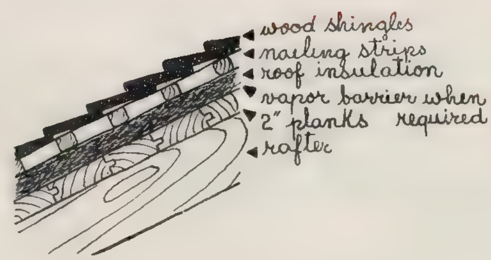
In either design, enough insulation should be used to limit the summer heat gain, expressed as the temperature rise on the ceiling surface, to the minimum. Otherwise the ceiling will heat the interior radiantly in summer, just as effectively as ceiling radiant heating works in winter.

When the underside of a sloping roof is insulated (or acoustically treated) as shown, vapor control requires either (1) a vapor porous roofing, (2) a vapor barrier plus extra-thick insulation above the deck or (3) limitation of indoor moisture in cold weather. Igor B. Polevitzky, architect.

ROOFS: wood deck
with exposed rafters

insulated above deck

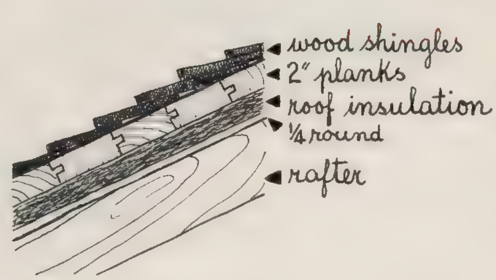
		none	1	1½	2
INSULATION THICKNESS, Inches		**none**	**1**	**1½**	**2**
CONDUCTANCE "C"			0.25	0.17	0.13
ALL ZONES					
HEAT TRANSMISSION "U"		**0.23**	**0.12**	**0.096**	**0.081**
% OF HEAT STOPPED by Insulation			48%	58%	64%
ZONE I					
COMFORT RATING	winter	59.5°	64.5°	65.6°	66.3°
	summer	88.1°	82.1°	80.8°	79.9°
ECONOMY RATING			$23.40	$28.20	$31.50
OCCUPANCY-MOISTURE RATING		12%*	37%	46%	52%
ZONE II					
COMFORT RATING	winter	61.9°	65.7°	66.6°	67.1°
	summer	88.1°	82.1°	80.8°	79.9°
ECONOMY RATING			$15.60	$18.80	$21.00
OCCUPANCY-MOISTURE RATING		22%*	47%	54%	60%
ZONE III					
COMFORT RATING	winter	63.0°	66.3°	67.0°	67.5°
	summer	88.1°	82.1°	80.8°	79.9°
ECONOMY RATING			$7.80	$9.40	$10.50
OCCUPANCY-MOISTURE RATING		28%*	53%	59%	65%



*With no insulation and no vapor barrier, condensation on roofing paper under shingles is controlling.

insulated below deck between rafters

		none	1	1½	2
INSULATION THICKNESS, Inches		**none**	**1**	**1½**	**2**
CONDUCTANCE "C"			0.25	0.17	0.13
ALL ZONES					
HEAT TRANSMISSION "U"		**0.29**	**0.14**	**0.11**	**0.087**
% OF HEAT STOPPED by Insulation			54%	64%	70%
ZONE I					
COMFORT RATING	winter	56.5°	63.8°	65.1°	66.0°
	summer	91.7°	83.0°	81.4°	80.3°
ECONOMY RATING			$33.90	$40.00	$44.20
OCCUPANCY-MOISTURE RATING		See analysis on preceding page			
ZONE II					
COMFORT RATING	winter	59.5°	65.2°	66.2°	66.9°
	summer	91.7°	83.0°	81.4°	80.3°
ECONOMY RATING			$22.60	$26.70	$29.50
OCCUPANCY-MOISTURE RATING		See analysis on preceding page			
ZONE III					
COMFORT RATING	winter	61.0°	65.8°	66.7°	67.3°
	summer	91.7°	83.0°	81.4°	80.3°
ECONOMY RATING			$11.30	$13.40	$14.70
OCCUPANCY-MOISTURE RATING		See analysis on preceding page			



ROOFS: wood deck, with ceiling on underside of rafters

ROGER STURTEVANT

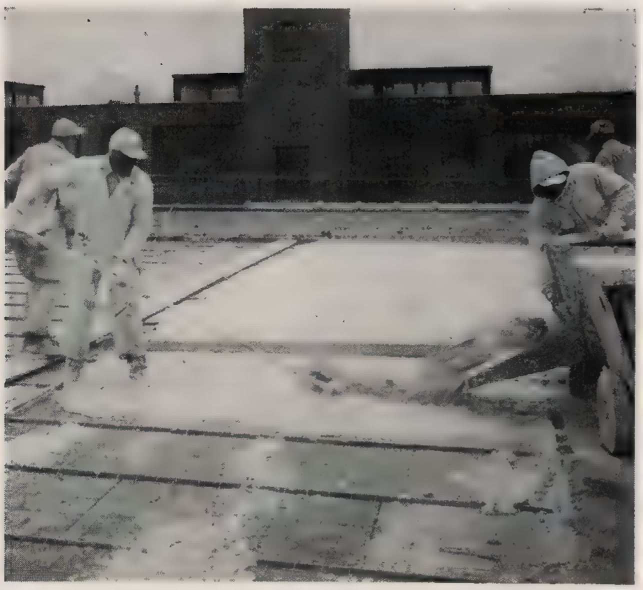
When the ceiling is applied to the under side of the rafters or joists in sloping or flat roof, insulation, a vapor barrier and eave-to-eave ventilation can be provided for maximum comfort and performance. Anshen & Allen architects.

Pitched roofs and shed roofs of low slope, with the ceiling line following the angle of the roof, are popular with many architects designing modern "solar" houses, one-story schools, suburban medical centers, and similar buildings. Here the ceiling is used for light reflection and is customarily attached to the under side of the rafters.

Insulation may be used either above the deck or on the ceiling finish. If the former position is used there can be no venting of the rafters, which, under adverse conditions, may be subjected to dry rot. Vapor control also would require a vapor barrier on the deck beneath the insulation, plus enough insulation to keep this barrier warm and to offset the insulating value of the ceiling and the "dead" air space.

Better practice is to apply the insulation just above the ceiling finish, between the rafters, and to ventilate thoroughly each space between the rafters by means of continuous eave and ridge vents. A vapor barrier is essential in Zone I and highly desirable in Zone II. It should be located between the ceiling finish and the insulation.

ROOFS: with gypsum or light-weight aggregate concrete on insulating form board



Insulating form board, under a poured deck of gypsum or lightweight aggregate concrete, affords acoustical treatment, insulation, formwork and ceiling in one operation. Suitable for dry occupancies.

A low-cost, multi-purpose roof construction that is growing in popularity uses an insulating board as a permanent form, supported on small steel sub-purlins of bulb-headed tees, on which is cast a gypsum or light-weight aggregate concrete slab, suitably reinforced. When the form board thus used has sound-absorbing value, the combination provides insulation, acoustical treatment, a ceiling and includes the cost of formwork, all in one operation. An insulated precast concrete unit has similar properties.

When the construction follows the details shown opposite (and used in the time-saver table) it is impractical to provide a properly located vapor barrier. Such construction is intended for "dry" occupancies only. In marginal cases the time factor (page 48) should be considered carefully. The designer may use his judgment as to the duration of moisture levels higher than those indicated and the consequences of periods when condensation might develop.

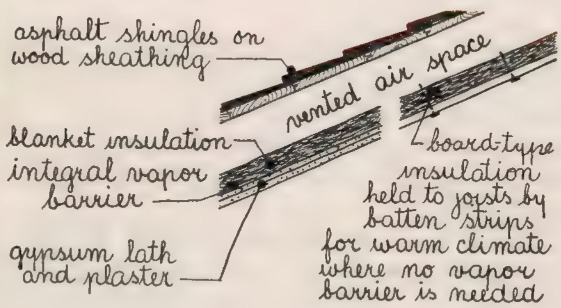
This construction can be used for medium- or high-moisture occupancies in any zone by applying roof insulation over a vapor barrier on the deck. The insulation thickness should be calculated as noted on page 70.

ROOFS: wood deck

with concealed rafters

insulation on under side of rafters

INSULATION THICKNESS, Inches		none	1	2	3
CONDUCTANCE "C"			0.27	0.14	0.090
ALL ZONES					
HEAT TRANSMISSION "U"		0.70	0.20	0.11	0.080
% OF HEAT STOPPED by Insulation			72%	84%	89%
ZONE I					
COMFORT RATING	winter	37.9°	61.0°	64.8°	66.3°
	summer	94.8°	82.2°	79.3°	78.1°
ECONOMY RATING			$108.00	$125.50	$132.70
OCCUPANCY-MOISTURE RATING		31%*	58%	73%	80%
ZONE II					
COMFORT RATING	winter	45.0°	63.0°	65.9°	67.1°
	summer	94.8°	82.2°	79.3°	78.1°
ECONOMY RATING			$72.00	$83.70	$88.50
OCCUPANCY-MOISTURE RATING		41%*	65%	78%	84%
ZONE III					
COMFORT RATING	winter	48.6°	64.0°	66.5°	67.5°
	summer	94.8°	82.2°	79.3°	78.1°
ECONOMY RATING			$36.00	$41.80	$44.20
OCCUPANCY-MOISTURE RATING		46%*	70%	82%	86%



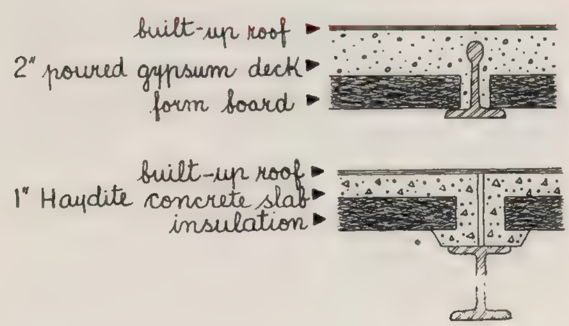
ROOFS: light slab

a: gypsum on ½″ gypsum form board

b: gypsum on 1″ insulating form board

c: light-weight concrete on insulating form board

		a	b	c
INSULATION THICKNESS, Inches		none	1	1
CONDUCTANCE "C"			0.23	0.25
ALL ZONES				
HEAT TRANSMISSION "U"		0.40	0.15	0.19
% OF HEAT STOPPED by Insulation			61%	52%
ZONE I				
COMFORT RATING	winter	51.6°	62.9°	61.2°
	summer	96.9°	84.0°	86.2°
ECONOMY RATING			$52.80	$44.70
OCCUPANCY-MOISTURE RATING		4%	3%	3%
ZONE II				
COMFORT RATING	winter	55.7°	64.5°	63.1°
	summer	96.9°	84.0°	86.2°
ECONOMY RATING			$35.20	$29.80
OCCUPANCY-MOISTURE RATING		10%	7%	7%
ZONE III				
COMFORT RATING	winter	57.7°	65.3°	64.1°
	summer	96.9°	84.0°	86.2°
ECONOMY RATING			$17.60	$14.90
OCCUPANCY-MOISTURE RATING		15%	11%	11%



NOTE: Heat transmission coefficients of deck material vary with suppliers and composition of material. Values in table are taken between supports and disregard conduction of reinforcing mesh and steel structural members.

CEILINGS: insulated, with ventilated space above

Any new building that will have a top-floor ceiling suspended or erected below the roof deck, can utilize the principle of the air-cooled roof and thus meet the summer sun heat problem which prevails in all parts of the United States.

The roof deck itself should be conceived as an umbrella over the building, rain-proof and capable of meeting snow and wind loads. It may be light in mass, as there is no value in creating high heat capacity to provide a heat lag between the top and under sides.

If any insulation is used at all on the roof deck, its value may be limited to reducing the sun heat load so that heat transfer by radiation across the loft space to the ceiling will be diminished. Such roof insulation should not require a vapor barrier in any climate if the loft is fully ventilated, because the air in the loft space should develop the same temperature and vapor pressure as the air above the roof.

The loft space should be as effectively ventilated to the outer air as the exterior design will permit. This calls for side-wall or eave louvres or vent openings plus ventilators in the mid area of the roof itself, so placed as to assure uniform air movement throughout the loft, whichever way the wind is blowing. Buildings shielded by adjacent structures may need mechanical ventilation of the loft space for maximum summer comfort and to remove excess vapor that might accumulate in winter.

All vents and louvres should be designed to prevent ingress of wind-driven snow or rain.

The ceiling construction should be designed to carry insulation adequate to minimize winter heat losses. In most cases a vapor barrier is desirable. It should be considered essential in all high-moisture occupancies in all zones; in normal and dry occupancies it is not required in Zone III but its need in Zones II and I will be governed in part by the moisture level indoors and the effectiveness of the ventilators in the loft.

To avoid fire hazards, all materials used in the loft should be non-combustible; otherwise where sprinkler protection is required, it should be the dry-pipe system since the piping will be exposed to freezing. Summer condensation, which might occur briefly on surfaces cooled during the night, can be countered by suitably protecting exposed steel or iron or by using non-ferrous metals. All of these considerations apply in ordinary loft space, hence the only extra cost for summer comfort is for vent openings or ventilating units, and the cost of these is offset by the fact that the insulation used on the ceiling can be of a much less expensive type than would be required above the deck.

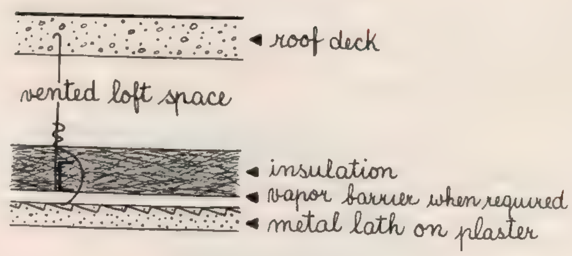
I. B. LINDENTHAL

Although the principle of ventilating unoccupied loft spaces under flat roofs has long been used, present day knowledge indicates that an increase in the net area of vents over past practices, coupled with adequate ceiling insulation, will increase comfort in the rooms immediately below during warm, sunny weather.

CEILINGS: insulated with ventilated space above

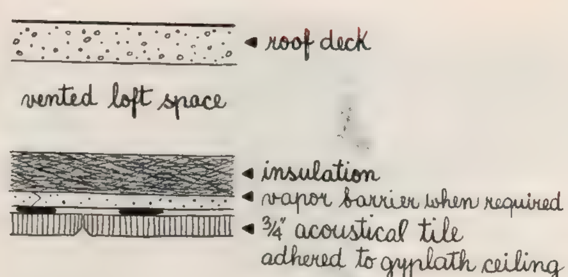
metal lath and plaster ceiling

INSULATION THICKNESS, Inches	none	3	4	6
CONDUCTANCE "C"		0.090	0.075	0.050
ALL ZONES				
HEAT TRANSMISSION "U"	0.80	0.081	0.071	0.048
% OF HEAT STOPPED by Insulation		90%	91%	94%
ZONE I				
COMFORT RATING winter	33.0°	66.3°	66.7°	67.8°
COMFORT RATING summer	96.9°	78.3°	77.9°	77.0°
ECONOMY RATING		$155.50	$157.80	$162.80
OCCUPANCY-MOISTURE RATING	25%*	83%	85%	90%
ZONE II				
COMFORT RATING winter	41.3°	67.1°	67.5°	68.3°
COMFORT RATING summer	96.9°	78.3°	77.9°	77.0°
ECONOMY RATING		$103.50	$105.10	$108.30
OCCUPANCY-MOISTURE RATING	35%*	86%	87%	92%
ZONE III				
COMFORT RATING winter	45.4°	67.5°	67.8°	68.5°
COMFORT RATING summer	96.9°	78.3°	77.9°	77.0°
ECONOMY RATING		$51.80	$52.60	$54.30
OCCUPANCY-MOISTURE RATING	41%*	89%	91%	94%



3/4" acoustical tile on gypsum lath ceiling

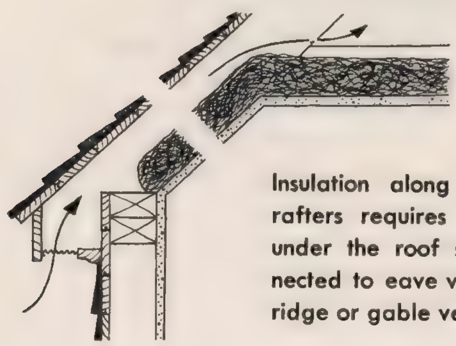
INSULATION THICKNESS, Inches	none	3	4	6
CONDUCTANCE "C"		0.090	0.075	0.050
ALL ZONES				
HEAT TRANSMISSION "U"	0.25	0.066	0.059	0.043
% OF HEAT STOPPED by Insulation		73%	76%	82%
ZONE I				
COMFORT RATING winter	58.9°	67.0°	67.3°	68.0°
COMFORT RATING summer	83.8°	77.7°	77.4°	76.8°
ECONOMY RATING		$39.30	$40.80	$44.10
OCCUPANCY-MOISTURE RATING	5%*	48%	52%	62%
ZONE II				
COMFORT RATING winter	61.1°	67.6°	67.9°	68.5°
COMFORT RATING summer	83.8°	77.7°	77.4°	76.8°
ECONOMY RATING		$26.20	$27.20	$29.40
OCCUPANCY-MOISTURE RATING	10%*	56%	60%	70%
ZONE III				
COMFORT RATING winter	62.4°	68.0°	68.2°	68.7°
COMFORT RATING summer	83.8°	77.7°	77.4°	76.8°
ECONOMY RATING		$13.10	$13.60	$14.70
OCCUPANCY-MOISTURE RATING	15%*	61%	64%	73%



*With no insulation and no vapor barrier, condensation on plaster surfaces is controlling. If loft space is not vented, condensation depends on roof deck and its insulation.

CEILINGS: under pitched roofs with ventilated attic space

Most economical and advantageous locations for insulation are those indicated above. When part of attic space is occupied, spaces "a" and "b" should be vented at eaves and connected to space "c".



Insulation along the slope of rafters requires a vent space under the roof sheathing, connected to eave vents below and ridge or gable vents above.

Continuous slots in soffit of eaves are recommended for ventilation of all roofs but are essential for hip roofs and on buildings where insulation follows the slope of the roof.

Most popular—and climatically the most logical—type of residential roof in America is the pitched roof forming an attic over the top-floor ceiling. From an insulation engineer's viewpoint, this is fortunate, for such structures can be easily insulated and properly ventilated, either in the original design, or by subsequent corrective measures.

Nevertheless many misunderstandings and errors have been found in actual practice. They are largely due to two factors: one, lack of knowledge of vapor control; the other, distrust of all-year ventilation because owners do not understand that adequate insulation can effectively offset heat losses to a cold attic.

Summer comfort, in all parts of the United States, can be enhanced by maximum ventilation of all unoccupied attic space, in accordance with the principles of the air cooled roof developed on page 56.

Winter vapor control, in Zones I and II at least, calls for attic ventilation equalling—and preferably exceeding the minimum requirements of FHA, given in the table on page 63.

Insulation of maximum practical all-year effectiveness should be used in attics, for both summer and winter value. There is so little difference in installed cost between a thick and a medium thick insulation, that the long-range comfort advantages far outweigh the slight economy of less than the best.

The preferred location for insulation is shown in the two diagrams at the left, above. This location facilitates correct application. Insulation should *not* be installed along the slope of the rafters *unless* eave ventilation is provided between each rafter space, and these spaces are connected together or otherwise continuously ventilated at or near the ridge.

Eave ventilation is so easily provided by cutting back the normal soffit trim and screening the resulting slot, that it should be used more extensively. A simple detail is shown at the left.

ICICLES AND SNOW DAMS

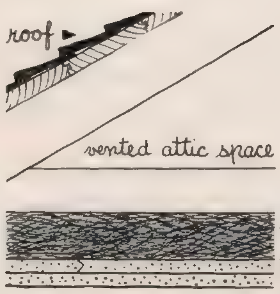
Icicles pendant from roof overhangs may be beautiful in the sun but they are hazardous and destructive.

Their appearance is usually accompanied by snow or ice dams on the roof above, and these are prolific causes of leaks in the roof. Both are formed by

CEILINGS: under vented attics

gypsum lath and plaster ceiling

INSULATION THICKNESS, Inches		none	2	3	4	6
CONDUCTANCE "C"			0.14	0.090	0.075	0.050
ALL ZONES						
HEAT TRANSMISSION "U"		0.70	0.11	0.080	0.068	0.047
% OF HEAT STOPPED by Insulation			83%	88%	90%	93%
ZONE I						
COMFORT RATING	winter	37.9°	64.8°	66.3°	66.9°	67.9°
	summer	94.8°	79.3°	78.1°	77.7°	76.9°
ECONOMY RATING			$125.70	$132.90	$135.30	$139.80
OCCUPANCY-MOISTURE RATING		31%*	72%	80%	82%	88%
ZONE II						
COMFORT RATING	winter	45.0°	65.9°	67.1°	67.6°	68.3°
	summer	94.8°	79.3°	78.1°	77.7°	76.9°
ECONOMY RATING			$83.80	$88.60	$90.20	$93.20
OCCUPANCY-MOISTURE RATING		41%*	77%	83%	86%	90%
ZONE III						
COMFORT RATING	winter	48.6°	66.5°	67.5°	67.9°	68.6°
	summer	94.8°	79.3°	78.1°	77.7°	76.9°
ECONOMY RATING			$41.90	$44.30	$45.10	$46.60
OCCUPANCY-MOISTURE RATING		46%*	83%	85%	88%	91%



*With no insulation and no vapor barrier, surface condensation is assumed to be controlling, but condensation may occur on under side of roof sheathing at occupancy-moisture ratings lower than those given.

non-uniform melting of snow. The overhangs or cornices, with any eave-troughing that may be used, are subject to outside air temperatures from above and below. The sun cannot warm up the soffit areas of the overhang. But the sun, usually aided by some heat leakage from the building, may melt the snow on the slope even before the air temperature rises above freezing.

This melting snow runs down the roof until it reaches cold snow at the eaves that has not melted. Here it is dammed up, sometimes forming a shallow pool just above the wall line of the building. This water seeps back under the shingles, often well above any flashing, and enters the building to cause stained or weakened plaster on the outer walls and ceiling beneath.

Both the Housing and Home Finance Agency and FHA recommend that roofing felt be installed well above the ordinary flashing line to minimize the chance of leaks due to snow or ice dams on the roof.

However, another additional corrective is associated with effective attic venting. If continuous eave vents are built-in to the cornice or overhang, they provide a wash of air on the under side of the roof deck that tends to equalize the temperature of the whole slope. This, in turn, reduces the chance that snow or ice dams, and hazardous icicles, will form at all.

Cold overhanging eaves often cause ice-dams, leaking roofs and hazardous icicles. Snow on the sloping roof is melted by sun and roof heat losses combined. At the eave melting is slower, forming a snow or ice dam. Overflow may back up under shingles and also form dangerous icicles. Eave vents, creating an air wash under the sheathing, reduce these hazards.

ROOFS: monumental

Auditoriums, churches, synagogues, mosques, memorial and other monumental buildings with roofs of special design ordinarily enclose such a great volume of space in proportion to the number of people occupying them, or such occupancy is for such relatively brief intervals, that condensation problems are comparatively rare.

Nevertheless, enough instances of trouble have been reported to warrant a brief discussion of the principles involved in the prevention or correction of condensation.

New buildings commonly maintain a high vapor content for the first year or two, due to the presence of immense quantities of water used in the concrete, masonry and plaster work. Ventilation is seldom provided in sufficient amount, or for a long enough time, to carry away this excess moisture.

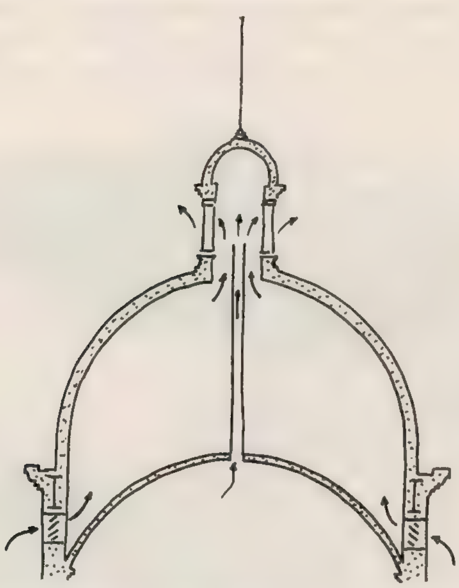
For example, a school gymnasium erected during the fall and early winter in New Hampshire, disgracefully rained upon the dedication audience one February evening. Until that occasion the roof and walls, though probably nearly saturated, had revealed no surface dampness. The large audience added just enough moisture to tip the balance, to the chagrin of the school board and the keen embarrassment of the architect.

However, when a study revealed the cause, it also developed that the school board had eliminated the ventilating equipment recommended by the architect. It was promptly installed and gradually corrected the condition. This case is typical of many buildings that show dampness during the first year or so of use; many good roofs have been replaced under guarantees simply because the building had not been adequately ventilated.

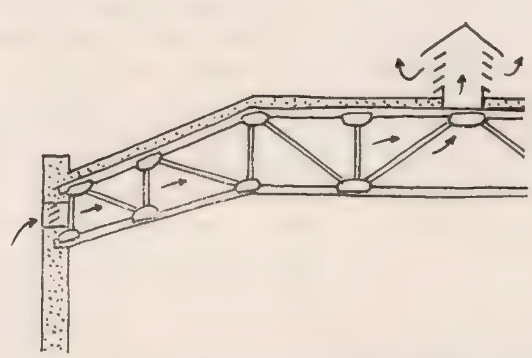
In another instance a synagogue with a decorative domed plaster ceiling under a higher structural dome was showing so much dampness that the paintings on the ceiling were being ruined. Here it was found that no ventilation was provided for the loft between the ceiling and the dome. A similar case was found in a Catholic church that had a dome patterned after St. Peter's in Rome. Very little ventilation was provided in the dome itself, but the warm humid air rising from the congregation was vented through the ceiling to the "empty" space above. In cold weather both places of worship suffered from hidden condensation.

The first solution to these problems is adequate ventilation of such lofts or vaults. The second may require a vapor barrier to prevent moisture travel through the plaster ceilings. Two common methods of venting are illustrated by the sketches above.

The need for insulation depends upon climate, duration of occupancy, the method of heating and the economic factors involved. It is usually more economical to insulate the suspended ceiling than the curved or sloping surfaces of the roof itself.



Domes should be designed for separate venting of the vaulted ceiling and the loft above it, especially if moisture level due to occupancy becomes high in cold weather.



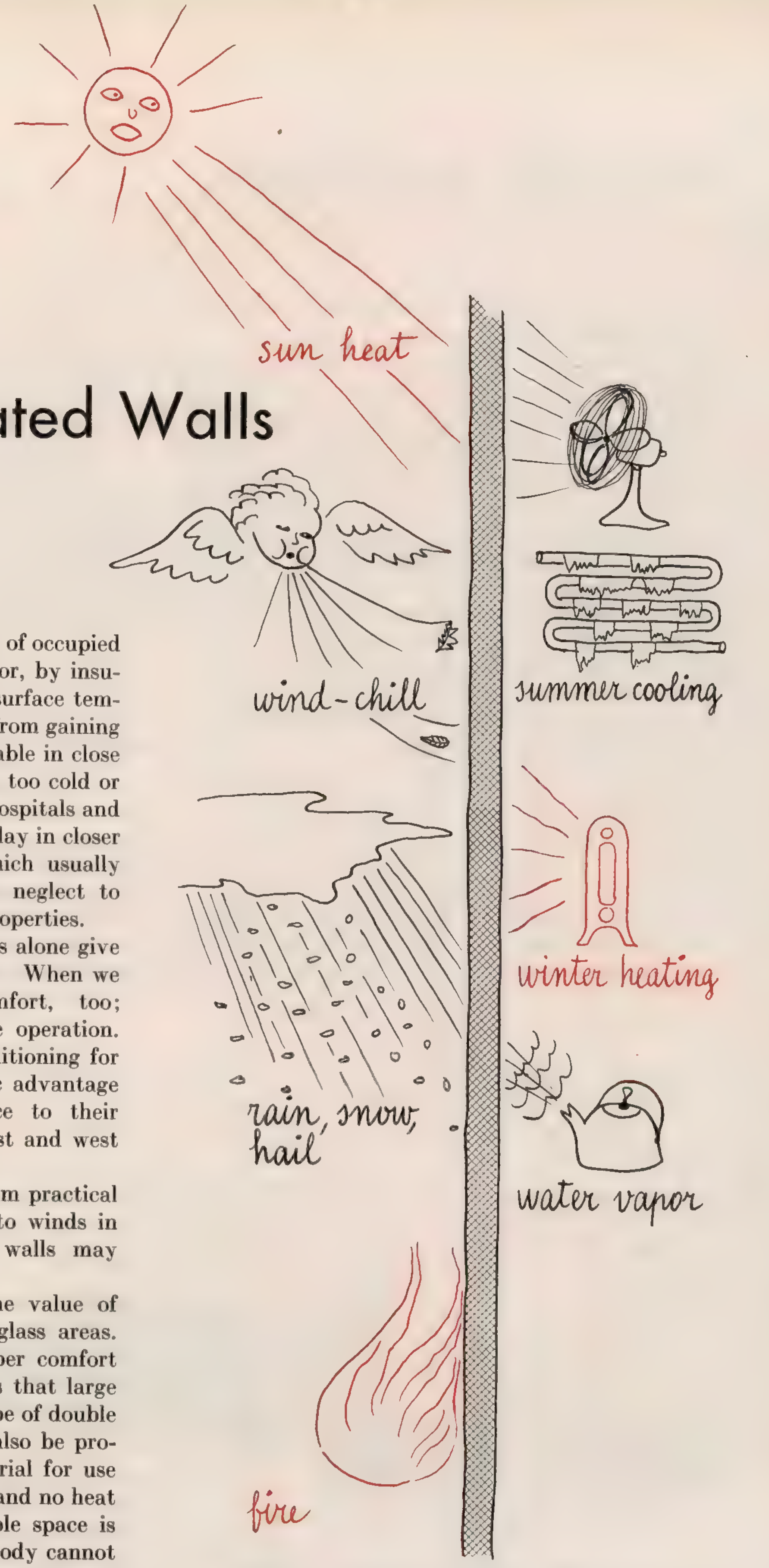
Ornamental ceilings suspended under any shape of roof are subject to damage by condensation unless the loft space above the ceiling is properly and adequately vented.

Design of Insulated Walls

I. B. LINDENTHAL

Control of indoor wall surface temperatures has a greater effect upon comfort than the temperatures of either ceiling or floor surfaces. For that reason, plus operating economies in heating or cooling, wall design deserves special study. Insulation, wall ventilation (air-cooled design) or shading are among the possible methods of controlling heat loss or gain. In the Houston Coca-Cola Bottling Plant by Stone & Pitts, architects, concrete grilles designed to shield auditorium exits also act as partial sun shades.

Design of Insulated Walls



Walls always resist these many forces to some degree. The designer's job is to combine materials that look well, perform well, take the least usable space at the lowest initial and operating costs.

Usable space can be gained in all types of occupied buildings where human comfort is a factor, by insulating the walls to maintain high inside surface temperatures in winter, and to prevent them from gaining heat in summer. We cannot be comfortable in close proximity to wall surfaces that are either too cold or too hot. Yet in homes, schools, offices, hospitals and many other structures, we work, rest or play in closer proximity to walls than to ceilings (which usually receive maximum insulation) and often neglect to design these walls with proper thermal properties.

In Zones I and II winter heating costs alone give economic justification for wall insulation. When we insulate to save fuel, we gain comfort, too; hence both benefits are enjoyed by one operation. In Zone III the trend toward air conditioning for summer comfort is making the economic advantage of insulated walls equal in importance to their comfort value, particularly for sunny east and west exposures.

Wind chill justifies the use of maximum practical amounts of insulation in walls exposed to winds in cold weather, in climates where other walls may not need so much.

The question always arises as to the value of insulation in walls designed with large glass areas. A rational answer is easily found. Proper comfort as well as good heating economy requires that large window areas, in Zones I and II at least, be of double or insulating glass and that these areas also be provided with draw curtains of heavy material for use at night when there is excessive heat loss and no heat gain. With any other construction, usable space is lost in cold weather because the human body cannot tolerate proximity to such cold surfaces without marked discomfort and possible hazards to health.

The value of insulating the remaining opaque wall areas thus depends on whether or not the heavy draperies cover them. If they do, their insulating value is at least as effective as it is across the glass area; if they do not, then the designer should use insulation to keep these exposed surfaces up to the comfort level.

WALLS: wood frame

Wood frame construction lends itself readily to the installation of effective insulation materials.

Where climatic factors require only slight improvement over the heat resistance of the wall without insulation, the use of rigid insulating boards, either as outer sheathing, inner finish, or both, is indicated. It is impractical to use more than 25/32″ thickness of insulation of this type because this replaces wood sheathing and permits the use, without extra cost, of standard door and window frames.

When climate, plus comfort and fuel economy dictate greater resistance to heat flow, or where, for reasons of cost or fire-safety gypsum sheathing is desired in place of insulating boards, the right degree of heat resistance can be obtained by the use of insulating blankets or fills, or suitable reflective materials, placed between the studs. The blankets are available in nominal 1″, 2″ and 3″ thicknesses giving corresponding degrees of insulating effectiveness. A fill insulation 3⅝″ thick (the actual depth of a so-called 2″ x 4″ stud) will give slightly better heat resistance than a 3 inch blanket plus an air space.

In areas of extreme cold, it may be advisable to use either fill or blanket insulations between the studs with insulating sheathing boards over them.

Vapor control makes a warm side vapor barrier (or the alternative of effective cold side venting) essential in Zone I, highly desirable in dwellings in Zone II and good, but not always necessary in Zone III.

FILL INSULATION

No occupancy-moisture ratings are given in these charts for 3⅝″ of insulation completely filling the air space, assumed to be blown in place, without a vapor barrier. The permissible relative humidity depends very largely upon the interior and exterior finishes and the amount of venting provided on the exterior.

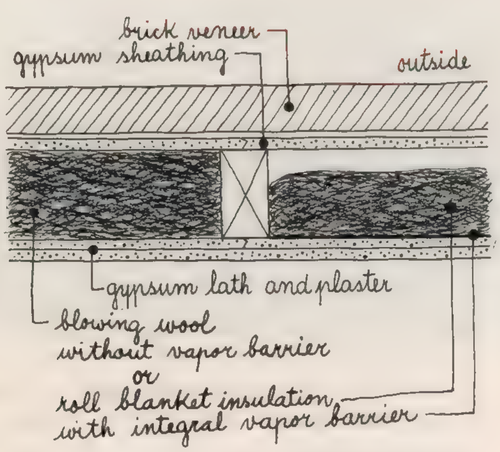
Research for the National Mineral Wool Association concludes that the following indoor relative humidities may be maintained "without excessive condensation" occurring within the wall when the indoor air is 70° F. However this term is not further defined, or the exact construction detailed.

Zone I	15%
Zone II	33%
Zone III	49%

Tests in the Climatometer at the Engineering Experiment Station, of Pennsylvania State College, indicate that these relative humidities are high unless design temperatures occur for only brief periods, or the cold side is well vented.

brick veneer on gypsum sheathing

INSULATION THICKNESS, Inches		none	1	2	3	3⅝
CONDUCTANCE "C"			0.27	0.14	0.090	0.075
ALL ZONES						
HEAT TRANSMISSION "U"		0.35	0.15	0.097	0.072	0.065
% OF HEAT STOPPED by Insulation			56%	72%	79%	81%
ZONE I						
COMFORT RATING	winter	51.2°	61.7°	64.7°	66.1°	66.5°
	summer	90.7°	81.9°	79.4°	78.3°	78.0°
ECONOMY RATING			$41.70	$53.40	$58.80	$60.60
OCCUPANCY-MOISTURE RATING		8%*	61%	73%	79%	**
ZONE II						
COMFORT RATING	winter	55.4°	63.6°	65.9°	66.9°	67.2°
	summer	90.7°	81.9°	79.4°	78.3°	78.0°
ECONOMY RATING			$27.80	$35.60	$39.20	$40.40
OCCUPANCY-MOISTURE RATING		16%*	68%	78%	83%	**
ZONE III						
COMFORT RATING	winter	57.4°	64.5°	66.5°	67.4°	67.6°
	summer	90.7°	81.9°	79.4°	78.3°	78.0°
ECONOMY RATING			$13.90	$17.80	$19.60	$20.20
OCCUPANCY-MOISTURE RATING		22%*	70%	81%	85%	**



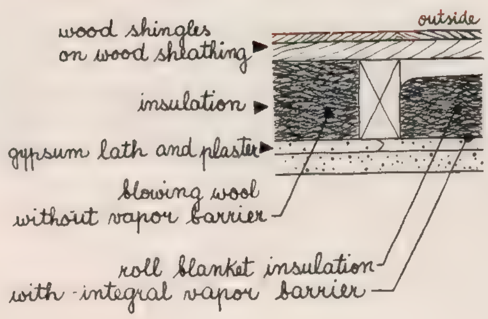
*With no insulation and no vapor barrier, rating is based on dew-point temperature at inner face of sheathing

**Assumed as blown insulation without vapor barrier. See notes on Fill Insulation in text above.

WALLS: wood frame

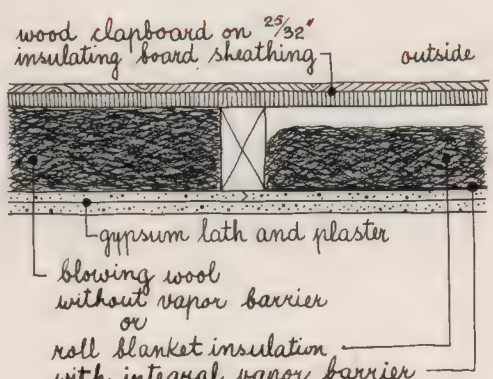
wood shingles on wood sheathing

INSULATION THICKNESS, Inches		none	1	2	3	3⅝
CONDUCTANCE "C"			0.27	0.14	0.090	0.075
ALL ZONES						
HEAT TRANSMISSION "U"		**0.25**	**0.13**	**0.087**	**0.066**	**0.061**
% OF HEAT STOPPED by Insulation			48%	65%	73%	76%
ZONE I						
COMFORT RATING	winter	56.5°	63.0°	65.2°	66.4°	66.7°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$25.50	$34.50	$39.30	$40.20
OCCUPANCY-MOISTURE RATING		19%*	67%	76%	82%	**
ZONE II						
COMFORT RATING	winter	59.5°	64.5°	66.3°	67.2°	67.4°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$17.00	$23.00	$26.20	$26.80
OCCUPANCY-MOISTURE RATING		29%*	74%	81%	85%	**
ZONE III						
COMFORT RATING	winter	61.0°	65.3°	66.8°	67.6°	67.8°
	summer	86.2°	80.8°	79.0°	78.0°	77.7°
ECONOMY RATING			$8.50	$11.50	$13.10	$13.40
OCCUPANCY-MOISTURE RATING		35%*	77%	83%	87%	**



wood clapboard on 25/32" insulating board

INSULATION THICKNESS, Inches		none	1	2	3	3⅝
CONDUCTANCE "C"			0.27	0.14	0.090	0.075
ALL ZONES						
HEAT TRANSMISSION "U"		**0.19**	**0.11**	**0.079**	**0.061**	**0.056**
% OF HEAT STOPPED by Insulation			42%	58%	68%	71%
ZONE I						
COMFORT RATING	winter	59.6°	63.9°	65.7°	66.7°	66.9°
	summer	83.6°	80.1°	78.6°	77.8°	77.5°
ECONOMY RATING			$17.10	$24.00	$27.90	$29.10
OCCUPANCY-MOISTURE RATING		30%*	69%	78%	82%	**
ZONE II						
COMFORT RATING	winter	61.9°	65.3°	66.6°	67.4°	67.6°
	summer	83.6°	80.1°	78.6°	77.8°	77.5°
ECONOMY RATING			$11.40	$16.00	$18.60	$19.40
OCCUPANCY-MOISTURE RATING		39%*	75%	82%	86%	**
ZONE III						
COMFORT RATING	winter	63.1°	65.9°	67.1°	67.8°	67.9°
	summer	83.6°	80.1°	78.6°	77.8°	77.5°
ECONOMY RATING			$5.70	$8.00	$9.30	$9.70
OCCUPANCY-MOISTURE RATING		45%*	79%	84%	87%	**



*With no insulation and no vapor barrier, rating is based on dew-point temperature at inner face of sheathing.

**See notes on Fill Insulation on page 88.

WALLS: wood panel, prefabricated

Prefabricated houses require insulation in all climates of the United States because their component structural materials (relatively thin studs and plywood or gypsum facings) offer somewhat less resistance to heat flow than orthodox frame construction.

Plywoods vary considerably in their resistance to vapor transmission, with the greatest vapor resistance usually found in the resin-bonded plywoods designed for exterior use. This circumstance makes it advisable to consider the design carefully, using a vapor barrier on the warm side, or vents through the outer skin, top and bottom, or a combination of both methods, to assure effective vapor control.

It is also desirable to study the design for balanced heat flow through both the solid sections and insulated sections. Ghost marking from unequal deposits of dust, either inside or out, became quite pronounced in some early work in the prefabricated housing field because the insulation used was either too effective for the solid sections, or was inadequate.

The insulating materials suitable for such panels are frequently made to order, as to size and thickness, to meet the special needs of each manufacturer of prefabricated buildings. Normally, a separate vapor barrier or a vapor resistant treatment should be applied during prefabrication.

WALLS: masonry, furred and plastered

Masonry walls requiring a plastered inside finish are usually "furred" with wood or metal strips to hold the plaster base away from the masonry. This space is desired to avoid dampness that might penetrate the masonry and has insulating value in itself. For any appreciable insulating value, the space should be at least ¾" deep, approximately the thickness of nominal 1" furring. Wood furring, being less conductive of heat than metal, is preferred where fire laws permit.

By making the furring strips slightly thicker than normal, and by suitably damp-proofing the inner face of the masonry, space can be provided for one or two inches of insulation in blanket form. The damp-proofing, however, should be vapor porous rather than vapor resistant. Although damp-proofing materials are seldom rated by their manufacturers for vapor porosity, thin applications of water-emulsion or cut-back asphalts or fibrated mastics are suitable.

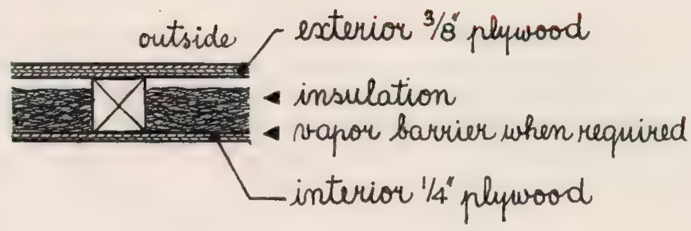
The values gained by such insulation are indicated in the accompanying table.

An alternative method is to adhere insulating blocks to the masonry, or attach them with adhered mechanical clips as in modern cold storage practice. The inner face of the insulation should be made vapor resistant before installing the lath and plaster. Thermal values will be approximately the same for equal thicknesses of insulation with either method.

WALLS: wood panel

prefabricated plywood, faced

INSULATION THICKNESS, Inches		none	1	2	3
CONDUCTANCE "C"			0.25	0.13	0.083
ALL ZONES					
HEAT TRANSMISSION "U"		0.42	0.16	0.096	0.074
% OF HEAT STOPPED by Insulation			63%	77%	82%
ZONE I					
COMFORT RATING	winter	47.2°	61.5°	64.8°	66.0°
	summer	94.0°	82.1°	79.3°	78.4°
ECONOMY RATING			$56.70	$69.90	$74.40
OCCUPANCY-MOISTURE RATING		5%*	64%	76%	81%
ZONE II					
COMFORT RATING	winter	52.3°	63.4°	65.9°	66.9°
	summer	94.0°	82.1°	79.3°	78.4°
ECONOMY RATING			$37.80	$46.60	$49.60
OCCUPANCY-MOISTURE RATING		12%*	71%	81%	85%
ZONE III					
COMFORT RATING	winter	54.8°	64.3°	66.5°	67.3°
	summer	94.0°	82.1°	79.3°	78.4°
ECONOMY RATING			$18.90	$23.30	$24.80
OCCUPANCY-MOISTURE RATING		17%*	74%	83%	87%

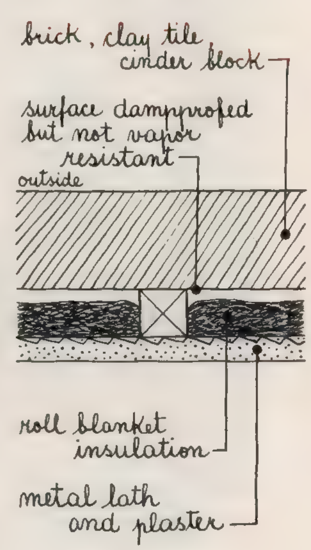


*With no insulation and no vapor barrier, rating is based on dew-point temperature at inner surface of exterior plywood.

WALLS: masonry

furred and plastered

		8" brick			8" clay tile			8" cinder block		
INSULATION THICKNESS, Inches		none	1	2	none	1	2	none	1	2
CONDUCTANCE "C"			0.27	0.14		0.27	0.14		0.27	0.14
ALL ZONES										
HEAT TRANSMISSION "U"		0.38	0.16	0.10	0.37	0.16	0.10	0.38	0.16	0.10
% OF HEAT STOPPED by Insulation			59%	74%		59%	74%		59%	74%
ZONE I										
COMFORT RATING	winter	49.1°	62.2°	64.5°	50.1°	62.3°	64.6°	49.5°	62.2°	64.6°
	summer	92.4°	82.2°	79.5°	91.6°	82.0°	79.5°	92.0°	82.1°	79.5°
ECONOMY RATING			$48.60	$61.20		$46.80	$58.50		$47.70	$60.30
OCCUPANCY-MOISTURE RATING		35%	66%	77%	37%	66%	77%	35%	66%	77%
ZONE II										
COMFORT RATING	winter	53.7°	63.3°	65.8°	54.5°	63.4°	65.8°	54.1°	63.3°	65.8°
	summer	92.4°	82.2°	79.5°	91.6°	82.0°	79.5°	92.0°	82.1°	79.5°
ECONOMY RATING			$32.40	$40.80		$31.20	$39.00		$31.80	$40.20
OCCUPANCY-MOISTURE RATING		45%	72%	82%	46%	73%	82%	45%	72%	82%
ZONE III										
COMFORT RATING	winter	56.0°	64.2°	66.4°	56.7°	64.4°	66.4°	56.3°	64.3°	66.4°
	summer	92.4°	82.2°	79.5°	91.6°	82.0°	79.5°	92.0°	82.1°	79.5°
ECONOMY RATING			$16.20	$20.40		$15.60	$19.50		$15.90	$20.10
OCCUPANCY-MOISTURE RATING		50%	76%	84%	52%	76%	84%	51%	76%	84%



NOTE: Furred air space assumed less than ½" with or without insulation.

WALLS: masonry, cavity type

When masonry walls were built massively, often well over a foot thick, they earned the reputation of being "warmer in winter and cooler in summer" than wood-framed walls without insulation. In recent years lighter construction has been generally adopted, and the old belief does not hold with masonry walls 12 inches thick or less.

In its general program for advancing clay masonry construction the Structural Clay Products Research Foundation has investigated and tested various ways of insulating masonry walls. Early in 1951 it announced the new SCR Insulated Cavity Wall and a special mineral wool insulating material made exclusively for it.

This wall is built with an outer and inner wythe of clay masonry, separated by a cavity that is usually 2″ wide. During erection the inner wythe is carried up ahead of the outer wythe and a vapor barrier is created on the cavity side of the inner wythe by coating this surface with a suitable asphalt-emulsion mastic as illustrated below. The new light-density glass mineral wool insulation is then poured from the bag into the cavity—without packing it down—when the outer wythe has been brought up to a conveneint level. Vertical joints are left open at the bottom and top of the outer wythe to provide vapor ventilation and to drain any wind-driven rain that might penetrate the face. The insulation has been tested under severe wind-and-water exposures and has been found to be non-settling, to drain rapidly and to allow effective vapor movement. This is the only type of insulation currently approved for this design.

The Research Foundation also found that its SCR wall can provide twice the thermal resistance of a furred and plastered masonry wall of equivalent thickness at a 10% saving in cost in most areas.

Incidentally, filling the cores of hollow concrete or clay masonry blocks or tile with insulating materials has often been tried but is not satisfactory in practice.

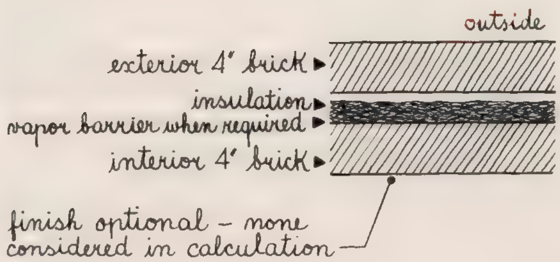
Massive masonry walls have been insulated with bonded or pre-formed mineral wool insulations, with or without a vapor-venting cavity formed on the cold side of the insulation. See illustrations on page 57 and on page 93 opposite. Cellular glass is another insulation appropriate for masonry walls. It constitutes its own vapor barrier.

Newest type of insulated cavity wall, developed and tested by the Structural Clay Products Research Foundation, is shown at left. This easily constructed wall employs a special light-density glass mineral wool insulation which permits the cavity to perform its function as a barrier to moisture penetration to the inner wythe. The insulation will not settle or deteriorate. Venting for vapor relief and weep holes for drainage of excess moisture are provided in the outer wythe. A water-emulsion asphalt vapor barrier is applied to the inner wythe as illustrated below.

WALLS: masonry

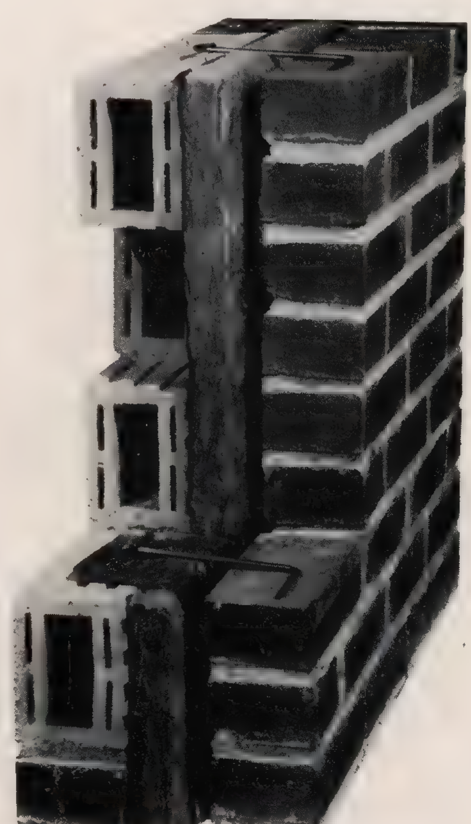
INSULATION THICKNESS, Inches	none	1	1½	2
CONDUCTANCE "C"		0.25	0.17	0.14
ALL ZONES				
HEAT TRANSMISSION "U"	**0.34**	**0.15**	**0.12**	**0.11**
% OF HEAT STOPPED by Insulation		50%	60%	64%
ZONE I				
COMFORT RATING winter	51.3°	62.1°	63.7°	64.2°
COMFORT RATING summer	90.5°	81.6°	80.2°	79.8°
ECONOMY RATING		$37.20	$44.70	$47.10
OCCUPANCY-MOISTURE RATING	5%*	52%	60%	62%
ZONE II				
COMFORT RATING winter	55.5°	63.8°	65.1°	65.5°
COMFORT RATING summer	90.5°	81.6°	80.2°	79.8°
ECONOMY RATING		$24.80	$29.80	$31.40
OCCUPANCY-MOISTURE RATING	10%*	61%	67%	69%
ZONE III				
COMFORT RATING winter	57.5°	64.7°	65.8°	66.1°
COMFORT RATING summer	90.5°	81.6°	80.2°	79.8°
ECONOMY RATING		$12.40	$14.90	$15.70
OCCUPANCY-MOISTURE RATING	15%*	65%	71%	73%

cavity type



*With no insulation and no vapor barrier, rating is based on dew-point temperature on inner surface of outer wythe. Calculations are based on construction using pre-formed insulation with an air space as in the sketch above.

Batt-type mineral wool insulations have long been used in cavity walls. A mock-up of a successful test wall, Toledo, Ohio, using a preformed insulation with an integral vapor barrier attached is shown at right. An air space in the cavity was provided to allow vapor venting and drainage of moisture to weep holes. The curtain walls at the base of aircraft assembly plants at Ft. Worth and Tulsa (below) used this same type of insulation with a vapor barrier backing. No air space was provided, because climatic and occupancy conditions indicated no venting or drainage problem.



WALLS: metal, for industrial buildings

For many industrial purposes a simple structural frame, overlaid with a wind- and rain-resistant shell of flat or corrugated metal, serves adequately. Foundries and other waste-heat-producing industries want no insulation to limit heat losses. Warehouses may create no vapor control problem.

When such buildings are used for occupancies which require winter heating, or protection from excessive sun heat, or when a vapor control problem arises, special consideration must be given to the use of insulation to provide the desired performance.

Sheet metals are inherently vapor resistant. They also have high thermal conductance. Little more than the heat resistance of the surface air films is counted in arriving at their average overall heat transmission rate (U) of about 1.50 Btu. These shells therefore form a cold side vapor barrier with little heat resistance.

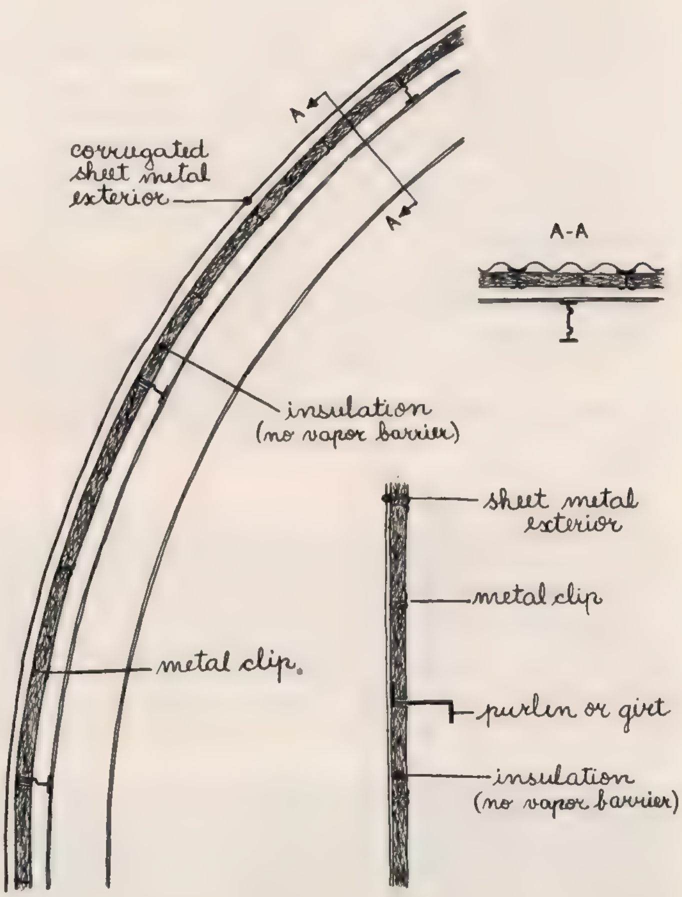
When insulated, the heat resistance can easily be increased materially but vapor control presents difficulties. The proper solution involves these considerations:

(1) When corrugated metal is used, the corrugations should be effectively vented to the outer air. When flat sheet metals are used, the insulation should be spaced away from the metal shell and this space vented freely to the outer air.

(2) The insulation should be thick enough to carry the entire job of resisting heat loss or gain, disregarding the slight value of the outer shelf.

(3) Where climatic and occupancy conditions indicate that vapor control is necessary, the insulation should have an effective vapor barrier on its warm side.

(4) If the metal structural frames and other "through metal" connections must be protected against heat loss or gain and surface condensation, the insulation and its vapor barrier should be installed over these members as well as over the intervening wall sections. This design, using wood furring strips spanning the distance between structural frames, or otherwise boxing around the frames, is assumed in the table opposite for method (b). If method (a) is used, condensation will occur on the exposed metal parts at the relative humidity given for uninsulated construction.



Prefabricated metal industrial buildings may be insulated in several ways depending upon the interior appearance desired and the occupancy moisture requirements. Photos show method (a) used in a welded frame structure at right and method (b) in a Quonset-type building on the opposite page.

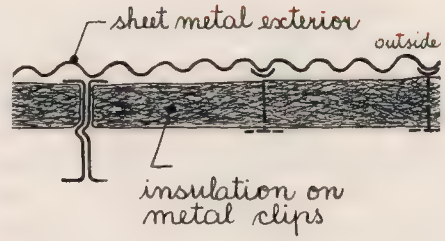
WALLS: metal

		a: none	a: 1	a: 2	b: none	b: 1	b: 2
INSULATION THICKNESS, Inches		none	1	2	none	1	2
CONDUCTANCE "C"			0.23	0.12		0.27	0.14
ALL ZONES							
HEAT TRANSMISSION "U"		1.50	0.20	0.11	0.58	0.19	0.11
% OF HEAT STOPPED by Insulation			87%	93%		68%	81%
ZONE I							
COMFORT RATING	winter	−11.8°	59.5°	64.3°	38.3°	59.9°	64.0°
	summer	138.0°	83.8°	79.8°	92.6°	80.6°	78.3°
ECONOMY RATING			$282.00	$301.50		$85.50	$102.00
OCCUPANCY-MOISTURE RATING		3%	2%	2%	32%*	52%	68%
ZONE II							
COMFORT RATING	winter	6.4°	61.7°	65.4°	45.4°	62.1°	65.3°
	summer	138.0°	83.8°	79.8°	92.6°	80.6°	78.3°
ECONOMY RATING			$188.00	$201.00		$57.00	$68.00
OCCUPANCY-MOISTURE RATING		7%	7%	6%	41%*	60%	74%
ZONE III							
COMFORT RATING	winter	15.4°	62.9°	66.3°	48.8°	63.3°	66.0°
	summer	138.0°	83.8°	79.8°	92.6°	80.6°	78.3°
ECONOMY RATING			$94.00	$100.50		$28.50	$34.00
OCCUPANCY-MOISTURE RATING		11%	9%	9%	47%*	65%	78%

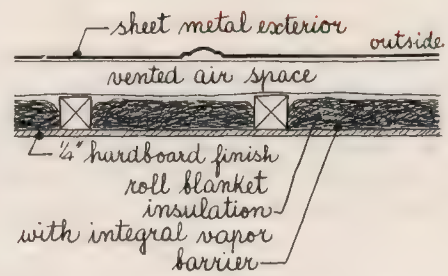
NOTE: All Method (b) calculations assume that an interior finish is provided. This construction is thermally superior to Method (a), hence Economy Ratings appear lower in Method (b). Without the interior finish, economy ratings for Methods (a) and (b) would be substantially the same.

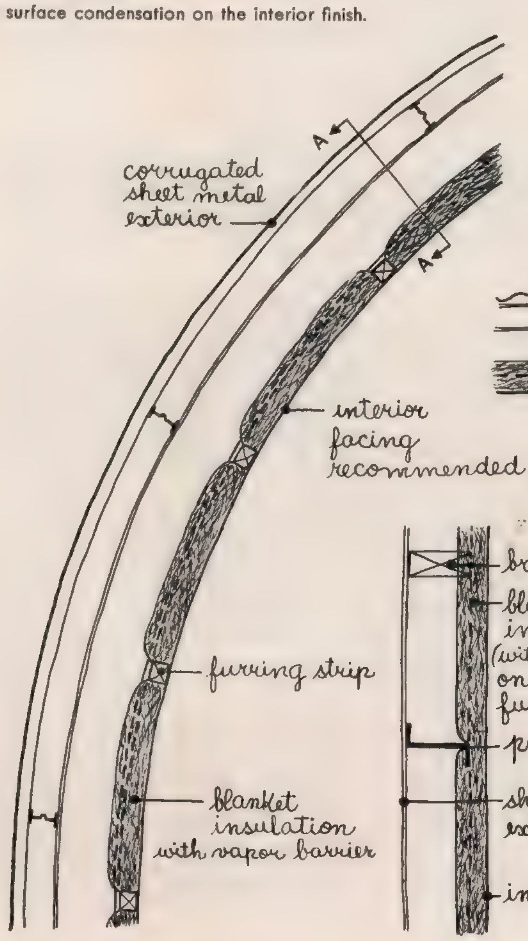
*These ratings are calculated for surface condensation on the interior finish.

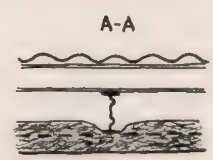
a: insulation clipped to exterior sheets

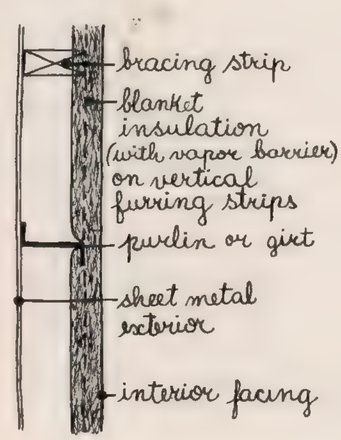


b: insulation on furring strips









WALLS: curtain and spandrel

Important savings in weight, construction costs and rentable or usable space have followed the introduction of light weight, relatively thin curtain and spandrel walls in place of the thick masonry commonly used in the past. These walls may be site-assembled, or pre-fabricated and installed as panels. They are usually made of metal, with an insulation in their cores, but non-metallic constructions, including corrugated asbestos-cement sheets, light weight clay masonry and light weight concrete masonry units are coming into use.

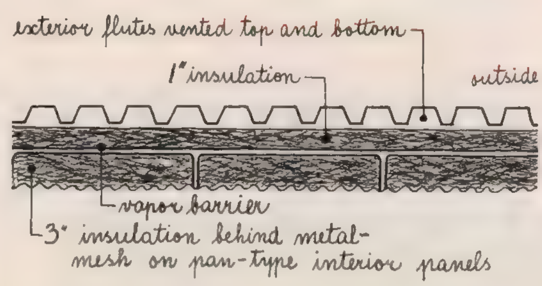
There are so many proprietary products entering this new field, and so many possible assemblies of standard materials, that only two field-assembled types can be analyzed in the tables; one designed for a dry climate and the other for a moderately humid climate, with dry occupancies in both cases. Generally the manufacturers of patented products have had their panels tested for thermal properties, and their catalogs should be used in making comparisons.

When specially designed assemblies are considered, the approximate thermal properties can be calculated by standard methods, but if metal connections extend from face to face, entire panels should be tested to establish the over-all heat transmission value (U) since it is impractical to appraise the heat movement through metals by ordinary mathematics.

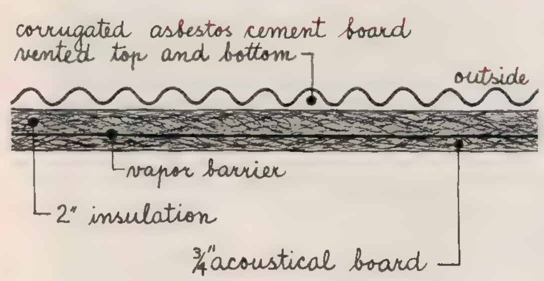
Air-cooled walls of this general type, in which the outer vertical channels are ventilated at top and bottom, have shown excellent performance in reducing solar heat loads and thus reducing air conditioning costs. In these early projects standard methods of calculation were used, omitting any value for the outer, ventilated shell. Apparently the results have been satisfactory, as substantiated by the exceptionally low air conditioning costs per man day, but unfortunately no scientific data have been accumulated to reveal their exact performance and degree of effectiveness.

		a		b	
INSULATION THICKNESS, Inches		none	4	none	2¾
CONDUCTANCE "C"			0.065		0.094
ALL ZONES					
HEAT TRANSMISSION "U"		0.82	0.060	1.50	0.084
% OF HEAT STOPPED by Insulation			93%		94%
ZONE I					
COMFORT RATING	winter	25.2°	66.7°	−12.0°	65.4°
	summer	99.8°	76.8°	120.5°	77.5°
ECONOMY RATING			$164.40		$306.00
OCCUPANCY-MOISTURE RATING		18%	7%	3%	34%
ZONE II					
COMFORT RATING	winter	35.3°	67.5°	6.3°	66.4°
	summer	99.8°	76.8°	120.5°	77.5°
ECONOMY RATING			$109.60		$204.00
OCCUPANCY-MOISTURE RATING		28%	15%	7%	44%
ZONE III					
COMFORT RATING	winter	40.1°	67.8°	15.5°	67.0°
	summer	99.8°	76.8°	120.5°	77.5°
ECONOMY RATING			$54.80		$102.00
OCCUPANCY-MOISTURE RATING		34%	20%	11%	50%

a: metal pan with fluted exterior
(designed for dry climate)



b: corrugated asbestos-cement
(designed for average climate)



Design of Insulated Floors

ROBERT DAMORA

In contrast to Standish Hall (page 52) Harvard University has its Graduate Center designed by The Architects Collaborative. Such structures exemplify the growing need for the effective insulation of floors that are exposed to air at outside design temperatures.

Design of Insulated Floors

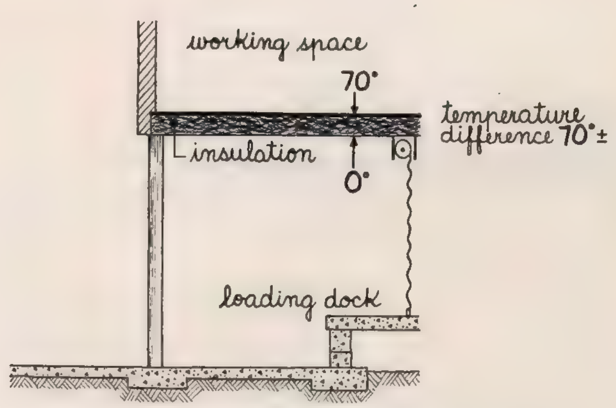
Wherever we work, play, or rest, our bodies are nearest to the floors of our buildings and are thus most immediately affected by their temperature. Cold floors carry away heat by conduction as well as by radiation and convection. They are hazardous to young children who play upon them, uncomfortable to all ages, and are prone to develop dampness due to condensation even though that dampness may be concealed by rugs and other vapor-porous floor coverings.

Most buildings have some floor area over unheated spaces, such as loading docks, garages, porches, recessed entrances. Modern heating plants for houses and small buildings are so efficiently insulated that even basement spaces containing these units frequently require use of heat to keep them comfortable. Unless heat is provided for this purpose, floors over basements may have to be classified as over unheated spaces.

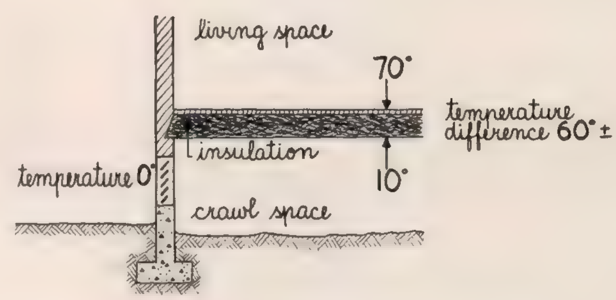
The temperature gradients commonly encountered in Zone II are shown in the three diagrams at the right. They will be greater in Zone I and less in Zone III but the principle remains the same. Note that earth temperatures at the depth locally adopted for water supply mains can be accurately determined by taking the tap water temperature. It seldom is found to be below 45°, even in severe winters, and commonly is 55° or higher.

These temperature gradients should govern the amount of insulation required.

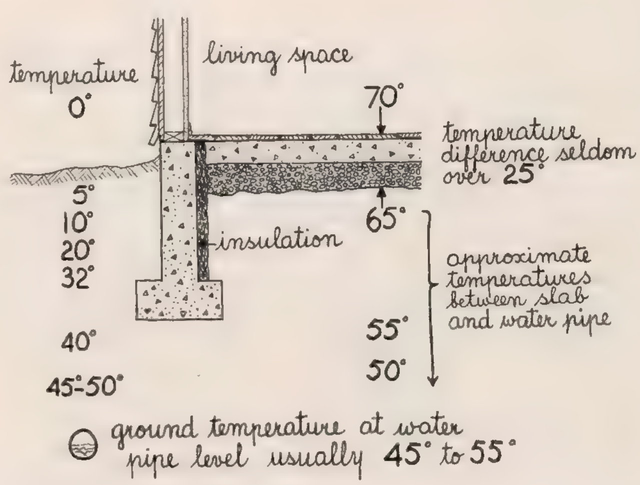
Vapor control, where significant, calls for a vapor barrier above the insulation, not below it. This seems to run counter to the fact that exposed earth in crawl spaces is a source of troublesome moisture. That is true, but vapor pressures are low in the cold crawl areas so that vapor from indoors still seeks to pass through the floor to the colder air beneath. It is often impractical to install such a vapor barrier (except between rough and finished wood flooring in frame buildings), but loss of vapor to an unheated space below seldom causes trouble, hence the barrier may often be disregarded. As noted earlier, the moisture production from crawl spaces can be minimized by a covering of roofing paper plus adequate ventilation of the space.



Recessed loading docks, garages, porches or car ports with living or working space above (or below) require floor insulation to combat winter temperatures.



Living areas over unheated, properly-ventilated crawl spaces require floor insulation to meet winter outdoor design temperature plus about 10°.



Concrete floor slabs on the ground only require perimeter insulation because earth temperatures (attested by local water supply) are seldom more than 25° below room temperatures when measured under heated buildings.

FLOORS: wood frame, over unheated spaces

Floors exposed to outside air temperatures need just as much insulation as walls in the same climate zone, as they experience the same temperatures without benefit of solar heat.

Vapor control also follows identical principles except that it is often a simple matter to select cold side materials of high vapor porosity, or to actually vent them without fear of rain penetration so that a warm side barrier can be omitted.

In frame construction, where wood floors are commonly used, the vapor barrier can be laid between the sub-floor and finished floor. Or blanket-type insulations having their own vapor barriers may be installed with the vapor barrier upwards and held in place with wire mesh or other inexpensive supporting materials attached to the under side of the floor joists. Another low-cost method of insulating wood-framed floors where the surface appearance is not important is to use mineral wool boards nailed to the lower edges of the floor joists with roofing nails having large metal-capped heads. The insulating values will be approximately the same as for an equal thickness of insulation between the joists, since an enclosed air space is provided in both cases. However, mineral wool boards only ¾″ or 1″ thick are generally used.

FLOORS: masonry and metal

According to Bureau of Standards tests, masonry floors above unheated spaces have low comfort and thermal properties unless properly insulated. This is due, of course, to the high conductance of masonry. Although not tested, the same observation would hold for masonry-surfaced, metal-supported floors, for the same reason.

Insulation can be applied to the underside by means of adhered metal clips, which can also carry, if desired, a metal lath and cement-plaster finish.

Another method follows standard cold-storage practices. The insulation, of load bearing type, can be installed on the structural floor, and then a finish floor of masonry installed above it.

Vapor control is seldom required because the normal tendency is for the vapor to pass down through the floor to the colder space where vapor pressures are lower. Where needed, it can be provided by installing a vapor barrier on the top side of the insulation wherever the latter is located.

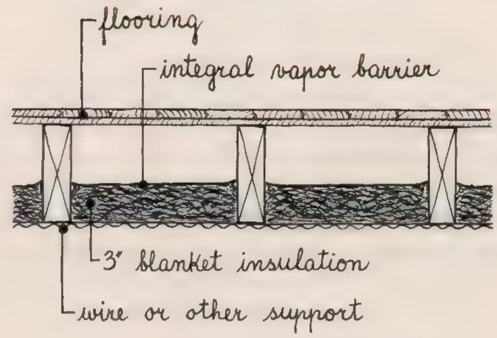
Insulating the under side of the floor slab, using metal clips, eliminates the need for expensive, load-bearing insulation within the slab.

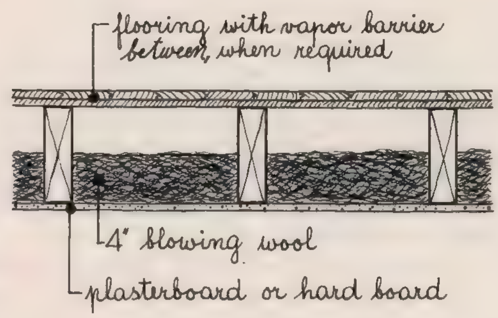
When the top of the floor must be insulated a load-bearing insulation, topped with concrete wearing floor, may be used.

FLOORS: wood frame

over unheated spaces

INSULATION THICKNESS, Inches	none	1	2	3	4
CONDUCTANCE "C"		0.27	0.14	0.090	0.075
ALL ZONES					
HEAT TRANSMISSION "U"	0.28	0.12	0.084	0.064	0.056
% OF HEAT STOPPED by Insulation		56%	70%	77%	80%
ZONE I					
COMFORT RATING winter	49.4°	60.9°	63.8°	65.2°	65.8°
ECONOMY RATING		$33.30	$41.40	$45.60	$47.40
OCCUPANCY-MOISTURE RATING	18%*	22%	37%	47%	73%*
ZONE II					
COMFORT RATING winter	54.0°	63.0°	65.1°	66.3°	66.8°
ECONOMY RATING		$22.20	$27.60	$30.40	$31.60
OCCUPANCY-MOISTURE RATING	28%*	32%	46%	56%	78%*
ZONE III					
COMFORT RATING winter	56.3°	63.9°	65.8°	66.8°	67.2°
ECONOMY RATING		$11.10	$13.80	$15.20	$15.80
OCCUPANCY-MOISTURE RATING	34%*	38%	52%	61%	81%*



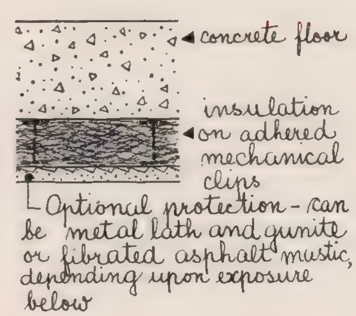


*Vapor barrier between flooring assumed for these ratings.

FLOORS: masonry

over unheated spaces

	concrete 3" thick				concrete 6" thick			
INSULATION THICKNESS, Inches	none	1	2	3	none	1	2	3
CONDUCTANCE "C"		0.23	0.12	0.077		0.23	0.12	0.077
ALL ZONES								
HEAT TRANSMISSION "U"	0.80	0.18	0.10	0.070	0.68	0.17	0.10	0.070
% OF HEAT STOPPED by Insulation		78%	88%	93%		75%	86%	90%
ZONE I								
COMFORT RATING winter	10.0°	56.7°	62.5°	64.8°	20.0°	57.3°	62.7°	64.9°
ECONOMY RATING		$135.60	$152.40	$162.00		$108.90	$124.80	$131.10
OCCUPANCY-MOISTURE RATING	9%	63%	77%	83%	14%	64%	77%	84%
ZONE II								
COMFORT RATING winter	23.5°	59.7°	64.2°	65.9°	31.0°	60.2°	64.3°	66.0°
ECONOMY RATING		$90.40	$101.60	$108.00		$72.60	$83.20	$87.40
OCCUPANCY-MOISTURE RATING	17%	70%	82%	87%	23%	71%	83%	87%
ZONE III								
COMFORT RATING winter	30.0°	61.1°	65.0°	66.5°	36.6°	61.5°	65.1°	66.6°
ECONOMY RATING		$45.20	$50.80	$54.00		$36.30	$41.60	$43.70
OCCUPANCY-MOISTURE RATING	22%	73%	84%	88%	29%	74%	85%	89%



FLOORS: masonry slabs on the ground

Amateur photographers have long known that they need to use ice with tap water to cool their developing solutions to the desired temperature in most parts of the United States. Yet the tap water accurately measures ground temperatures at water main depth and proves that winter cold does not penetrate deeply below the local frost level.

If we can prevent winter cold from creating a frost belt under a concrete slab floor in contact with the ground, it becomes obvious that the temperature difference between the desired room air (70° F.) and the ground beneath (45° F. to 55° F.) will seldom be over 25° F. This slight difference cannot justify the cost of insulation beneath the slab.

Even when the slab is heated by air or water, we design so that the upper surface temperature will not exceed 85° F. While this raises the temperature difference to around 30° F. to 40° F., this still compares to wall losses in the warmer parts of Zone III where sidewall insulation is only justified to counter high solar heat gain.

But the edges of such slabs are above outside grade and are therefore exposed to air temperatures that increase the differential to anywhere from 50° F. in Zone III up to 90° F. or more in Zone I. These spreads not only justify but practically demand insulation to prevent excessively cold floors, condensation along the outer marginal areas, and excessive waste of costly fuels.

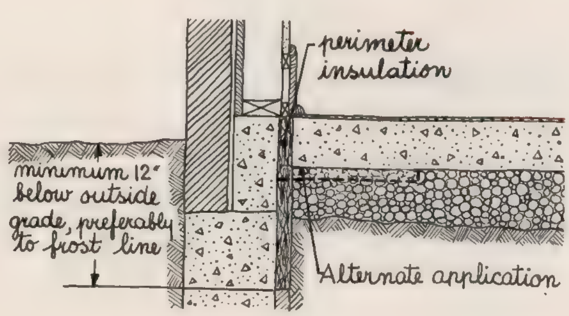
Perimeter insulation is therefore recommended for all concrete slab floors on the ground. It may be installed vertically down the inner face of the foundation wall, at least 12 inches below outside grade and preferably to frost depth; or it may be laid (at somewhat higher labor cost) in an L-shaped arrangement, vertically at the edge of the slab and then horizontally for a distance of 18″ to 24″ beneath the slab.

Vapor control is not necessary, since the trend of flow is downward. Nevertheless it is common practice to use a "capillary stop" of Slater's felt or roofing paper between the slab and the stone fill.

The National Warm Air Heating and Air Conditioning Manufacturers' Association, as a result of extensive research in warm air perimeter heating, recommends perimeter insulation 2″ thick, and considers 1-inch the absolute minimum. Unfortunately there are inadequate test data on materials over 1″ thick, hence the table below is limited to this one product thickness.

INSULATION THICKNESS, Inches	none	1
CONDUCTANCE "C"		0.27
ALL ZONES		
HEAT TRANSMISSION "F"	0.81*	0.55*
% OF HEAT STOPPED by Insulation		32%
ZONE I		
COMFORT RATING winter	44.0°	58.7°
ECONOMY RATING		$5.55**
OCCUPANCY-MOISTURE RATING	39%	67%
ZONE II		
COMFORT RATING winter	49.8°	61.2°
ECONOMY RATING		$3.70**
OCCUPANCY-MOISTURE RATING	48%	73%
ZONE III		
COMFORT RATING winter	52.6°	62.7°
ECONOMY RATING		$1.85**
OCCUPANCY-MOISTURE RATING	54%	78%

masonry slabs on the ground



*U-values not applicable. The given perimeter coefficient "F" is in units of Btu per hour per lineal foot of floor perimeter.
**Savings per 100 lineal feet of perimeter.
NOTE: Comfort Rating and Occupancy-Moisture Rating are based on temperature of the slab one foot from exterior walls.

Design Calculations

DESIGN CALCULATIONS:

A refresher course in solving insulation problems

Hidden in many standard handbooks and texts are reasonably simple methods of solving insulation problems with nothing more than ordinary arithmetic. Unfortunately, many scientists and technical men like to use the obscure lingo of higher mathematics and fill their formulas with Greek letters and the symbols of calculus.

Here, these standard calculation methods are presented in the arithmetic of the layman. If you can add, subtract, multiply and divide—or for the sake of speed, use an ordinary slide-rule—you can solve for yourself any of the commonly encountered problems relating to building insulations, vapor control and vapor ventilation. Good designing demands a knowledge of these factors in the early design stages.

Below are definitions of the terms and symbols necessarily used in thermal calculations.

Following that are texts and related reference tables dealing with the calculation of "U"-values, surface temperatures, vapor barrier temperatures, dew-points and occupancy-moisture limits, the vapor flow properties of building assemblies, and the ventilation required for vapor control. Although simplified wherever practicable, the data and methods are based on standard sources and authorities and are believed to be reliable as of the date of publication. It must be borne in mind, however, that both products and test methods are always subject to improvement. When new data appear from reliable sources, they should supersede corresponding data in these pages.

DEFINITIONS AND SYMBOLS

British Thermal Unit (Btu) A unit of heat defined generally as the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Degree Days (DD) A measure of the severity of a heating period, (usually an entire season) based on climatic conditions. It is found by determining from weather records for each day the difference between 65° F. and the mean temperature. The sum of these differences for all the days in the heating season is the Degree Days for that locality.

Dew-Point The temperature at which cooled air, with no change in pressure or amount of water vapor, becomes completely saturated (attains a relative humidity of 100%).

Emissivity (e) A rating of the ability of a material to give off heat as radiant energy. It is always equal to the amount of heat ***absorbed*** (not reflected), hence the sum of the emissivity and the reflectivity ratios, expressed as per cent, is always 100%. It is also defined as the ratio of heat radiated by a material to that of a "black body" under similar conditions. See Reflectivity. It is applicable only when the material faces an enclosed air space.

Humidity, Absolute The weight of water vapor, in pounds, per cubic foot of air.

Humidity, Relative This indicates, as a percentage, the amount of moisture that air of a given temperature is actually holding in vapor form as compared to what it could hold at that same temperature when fully saturated. Technically, it is the ratio of the actual vapor pressure in the space at a given temperature to the saturation vapor pressure at the same temperature.

Isotherm Usually refers to a line joining points of equal temperature.

Overall Heat Transmission Coefficient (U) A unit expressing heat passage through a complete building section, including air films. Technically, it is heat transmission in Btu per hour, per square foot, per degree F of temperature difference from air to air for a composite building section. It is the reciprocal (i.e., divided into 1) of the total resistance of the section, 1/R. It is used as a basis for determining transmitted heat loss or gain.

Perm A vapor transmission rate of 1 grain of water vapor per square foot, per hour, per inch of mercury pressure difference.

Reflectivity A term describing the ability of a material to reflect heat moving by radiation through air. It is expressed as the ratio of radiant heat reflected by a material to that of a "black body" (a theoretical body that absorbs all radiation falling on it) under similar conditions. No symbol is used as ratings are based on ***emissivity.*** (See above.)

Relative Humidity See Humidity, Relative.

Rep Reciprocal of ***Perm*** (i.e., Perms divided into 1).

Surface Air Film Coefficient (f) The amount of heat flow in Btu per square foot per hour between an exposed surface of a material and the adjacent air; f_i – inside surface film coefficient, f_o – outside surface film coefficient. It is a measure of the conductance of heat through the air film that clings to all surfaces. The resistance of such films is expressed as 1/f.

Therm A unit of 100,000 Btu of heat.

Thermal Conductance (C) A unit specifying the amount of heat, in Btu's per hour, that passes through a square foot of material which has a ***given thickness*** and one Fahrenheit degree of temperature difference between its surfaces. Used for comparing insulating efficiencies of materials with varying but stated thicknesses or those which are composed of two or more basic materials. Examples: surface-coated insulations, shingles, plywood, structural blocks.

Thermal Conductivity (k) A unit expressing the amount of heat, in Btu's per hour, that passes through a square foot of material which is ***exactly one inch thick*** and has one Fahrenheit degree of temperature difference between its surfaces. Used for comparing insulating efficiencies of materials which do not vary in composition, such as uncoated insulation, concrete, wood.

Thermal Resistance (R or 1/C) The reciprocal (i.e., divided into 1) of Thermal Conductance. Used in calculating overall heat transmission coefficients. When both resistances and resistivities are added, the letter R is used as a symbol for both. See Thermal Resistivity.

Thermal Resistivity (r or 1/k) The reciprocal (i.e., divided into 1) of Thermal Conductivity. Used in calculating overall heat transmission coefficients. See Thermal Resistance.

Vapor Barrier A material that does not readily permit the passage of water vapor. Normally, a material rated at one **perm** or less.

Vapor Permeability A rating of a material giving the amount of water vapor (in grains transmitted per square foot, per hour, per inch of mercury pressure difference) that passes through an **inch-thickness** of the material. Unit: **Perm-inch.**

Vapor Permeance The same as Vapor Permeability except that ***permeance,*** like ***conductance,*** is a rating of the material as tested, regardless of thickness. Unit: **Perm.**

Vapor Pressure That part of the total pressure which is exerted by the water vapor in the air.

Vapor Resistance Reciprocal (i.e., divided into 1) of Vapor Permeance. A rating of the resistance of a material to the passage of water vapor. Unit: **Rep.**

Vapor Resistivity Reciprocal (i.e., divided into 1) of Vapor Permeability. Resistance of a one-inch thickness of material to the passage of water vapor. Unit: **Rep/inch.**

DESIGN CALCULATIONS:

For heat control

Most materials used in building construction have been tested to establish how much heat they will transmit under standard conditions. These evaluations are subject to manufacturing and testing tolerances as described on page 111 and require some judgment in their final application. For calculation purposes, published test values are normally accepted.

Heat transmission coefficients are usually given as conductivities (k) or conductances (C). These have their counterparts: resistivity (r) or resistance (R). Each is the reciprocal of its counterpart as given in the definitions on the opposite page. The k or C value of a material is a handy basis for comparing thermal properties, but these values cannot be added to find the conductance of a building section made up of different materials. Resistances can be added, therefore they are easiest to use in heating calculations.

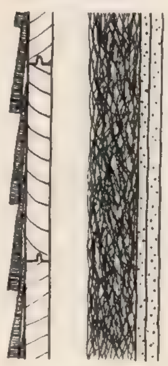
The rate of heat transmission (U) of a wall, floor, ceiling or roof is the fundamental fact needed in all heating, air conditioning and insulation problems. This value is found by either of two methods, depending on the type of materials employed.

To find Overall Heat Transmission Coefficient, U, — using ordinary, non-reflective materials

A very simple procedure is followed when customary building materials and insulations of the "trapped air" type are employed. No formulas are required and all necessary data can be drawn from Table 1 (page 107) or from test data for specific brands of insulation not listed.

1. List all component elements of a building section (including air spaces 3/4" or greater) beginning with the surface air film resistance of one face and ending with the surface resistance of the other face.
2. Against each component (except surface air films) show the thickness involved (actual, not nominal) unless test values are given as conductances.
3. Against each component, list the resistance for the thickness shown. See Table 1 for values. Resistivities can be multiplied or divided to adjust for thickness. For example, if the resistivity (for 1") is 3.70, then the resistance of 1/2 inch would be 1.85 and of 2 inches, 7.40.
4. Add the resistances.
5. Divide the total resistance into 1.00 to find the Overall Heat Transmission Coefficient – U.

EXAMPLE:



	Resistances
$1/f_o$ – outside surface air film, 15 mph wind	.17
yellow pine lap siding	.78
building paper	.18
wood sheathing, fir, actual 25/32"	.98
air space, ordinary materials, 1 5/8"	.91
insulation, mineral wool, 2"	7.40
gypsum lath, 3/8"	.27
gypsum plaster, 1/2"	.15
$1/f_i$ – inside surface air film, still air	.61
R_T – total resistance	11.45

$$U = \frac{1}{R_T} = .087$$

To find Overall Heat Transmission Coefficient, U, — using reflective materials

Much more complex calculations are involved when a reflective material is employed as insulation within the air spaces of a building assembly. The following procedure is summarized from FHA Technical Circular No. 7, revised to January, 1947.

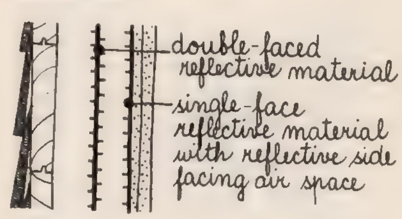
The amount of heat transferred across an enclosed air space faced one or both sides with reflective material varies with the temperature difference across the air space, the position of the air space and direction of heat flow, the width of the air space, the emissivity of the surfaces enclosing the air space, the shape of the air space, and to a negligible degree, with changes in the mean temperature of the air space.

The emissivity of the reflective material must be known in order that the calculation of the overall heat transmission coefficient will be accurate. Some reflective materials on the market have an emissivity higher (less reflective) than the emissivity of .05 given in the Heating, Ventilating, Air Conditioning Guide, ASHVE, for bright aluminum foil.

The following procedure should be followed in determining the overall heat transmission coefficient of a building section containing air spaces faced one or both sides with reflective material:

1. Determine the sum of the resistances (R) of the building section components other than the air spaces faced with reflective material as in this example:

EXAMPLE:



	Resistances
outside surface – $1/f_o$	.17
Y. P. lap siding	.78
25/32" fir sheathing with building paper	1.16
1/2" plaster on 3/8" gyplath	.42
inside surface – $1/f_i$	.61
Sum of resistance, R =	3.14

2. Determine the effective emissivity (E) of each air space faced with reflective material. The emissivity of the reflective surface must be known. The emissivity of an ordinary surface such as wood, plaster, gypsum lath, concrete, or tile may be assumed to be .90. The following formula should be used to determine the effective emissivity of each air space.

$$E = \frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1}$$

E = Effective emissivity of a single air space.
e_1 = Emissivity of one surface facing air space.
e_2 = Emissivity of other surface facing air space.

EXAMPLE: In the example building section the reflective material is of a type such as bright aluminum foil having an emissivity of .05; the ordinary surface has an emissivity of .90. For the space faced one side with ordinary material and one side with .05 reflective material:

$$E = \frac{1}{\frac{1}{.90} + \frac{1}{.05} - 1} = \frac{1}{20.11} = .0497$$

For the space faced both sides with .05 reflective material:

$$E = \frac{1}{\frac{1}{.05} + \frac{1}{.05} - 1} = \frac{1}{39} = .0256$$

3. Determine the average effective emissivity (E_a) of the air spaces faced with reflective material. The effective emissivities of the individual air spaces are added and divided by the number of air spaces.

$$E_a = \frac{E + E}{N}$$

E_a = Average effective emissivity
E = Effective emissivity of single air space
N = Number of air spaces faced with reflective material

EXAMPLE:

$$E_a = \frac{E + E}{N}$$

$$E_a = \frac{.0497 + .0256}{2} = \frac{.0753}{2}$$

E_a = .03765 Use .038

4. Determine the average temperature difference (T_d) across the individual air spaces faced with reflective material. The following formula should be used to determine the average effective temperature.

$$T_d = \frac{T_i - T_o}{N + RK}$$

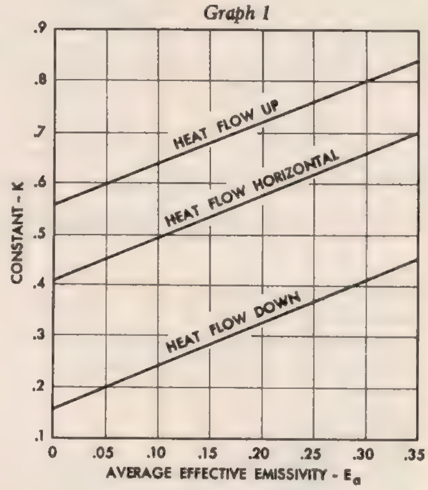
T_d = Average temperature difference across the individual air spaces faced with reflective material, °F.
T_i = Inside design temperature, °F.
T_o = Outside design temperature, °F.
N = Number of air spaces faced with reflective material.
R = Sum of resistances of building section components other than the air spaces faced with reflective material.
K = Constant K selected from Graph 1 according to direction of heat flow and average effective emissivity E_a.

EXAMPLE:
Inside design temperature, T_i = 70° F.
Outside design temperature, T_o = –10° F.
N, Number of air spaces faced with reflective material = 2
R, Determined in paragraph 1 = 3.14
K, selected from Graph 1 for heat flow horizontal and average emissivity E_a of .038 = .44

$$T_d = \frac{T_i - T_o}{N + RK} = \frac{70 - (-10)}{2 + 3.14 \times .44}$$

$$= \frac{80}{3.38} = 23.7° \text{ F.}$$

Graph 1

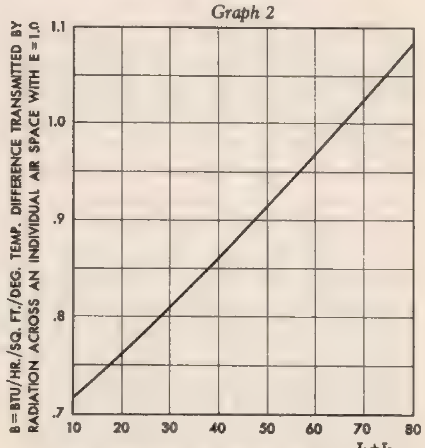


5. Determine average resistance (R_a) of the air spaces faced with reflective material. The following formula should be used to determine the average resistance:

$$R_a = \frac{1}{E_a \times B + D}$$

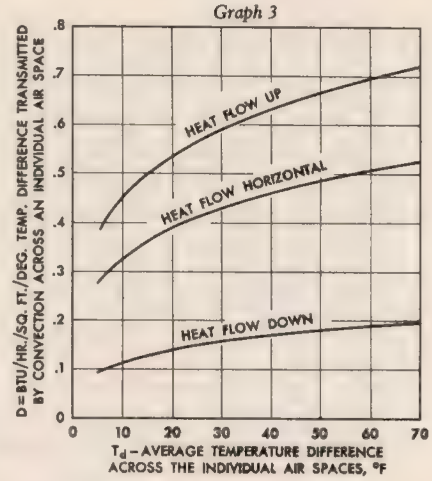
R_a = Average resistance of individual air spaces faced with reflective material.
E_a = Average effective emissivity.
B = Btu/hr./sq. ft./deg. temp. transmitted by radiation across an individual air space with effective emissivity of 1.0. Selected from Graph 2 according to mean temperature of building section. Mean temperature is secured by adding T_i and T_o and dividing by 2.

Graph 2



D = Btu/hr./sq. ft./deg. temp. difference transmitted by convection across an individual air space. Selected from Graph 3 according to direction of heat flow and average temperature difference across the individual air spaces T_d.

Graph 3



EXAMPLE:
Inside design temperature T_i = 70° F.
Outside design temperature T_o = –10° F.

$$\frac{T_i + T_o}{2} = \frac{70 + (-10)}{2} = \frac{60}{2}$$

= 30° F. Mean temperature
E_a, Calculated in paragraph 3 = .038.
B, Selected from Graph 2 for mean temperature of 30° F. = .807
D, Selected from Graph 3 for heat flow horizontal and T_d of 23.7° F. = .405

$$R_a = \frac{1}{E_a \times B + D}$$

$$R_a = \frac{1}{.038\ (.807) + .405} = \frac{1}{.031 + .405}$$

$$= \frac{1}{.436} = 2.295$$

6. Calculate the overall heat transmission coefficient (U) of building section. The following formula should be used to calculate the overall heat transmission coefficient.

$$U = \frac{1}{R + NR_a}$$

U = Overall heat transmission coefficient, Btu/hr./sq. ft./deg. temp. difference.
R = Sum of resistance of building section components other than the air spaces faced with reflective material.
N = Number of air spaces faced with reflective material.
R_a = Average resistance of individual air spaces faced with reflective material.

EXAMPLE:
R, Determined in paragraph 1 = 3.14
N, Number of air spaces faced with reflective material = 2
R_a, Determined in paragraph 5 = 2.295

$$U = \frac{1}{R + NR_a}$$

$$U = \frac{1}{3.14 + 2\ (2.295)} = \frac{1}{3.14 + 4.59}$$

$$U = \frac{1}{7.73} = .129 \quad \underline{\text{Use } .13}$$

Table 1: *Heat transmission coefficients*

All values in Btu per hour per square foot per °F. temperature difference.

Class	Material	Description	Conductivity k (for 1" thickness)	Conductance C (for given thickness)	Resistivity 1/k or r (for 1" thickness)	Resistance 1/C or R (for given thickness)
AIR FILMS	Inside—or still air	Ordinary materials—				
		heat flow horizontal		1.65		.61
		heat flow up		1.95		.51
		heat flow down		1.21		.83
	Outside—15 mph wind	Ordinary materials		6.0		.17
AIR SPACES	Ordinary material both sides	Vertical—¾" or more in width		1.10		.91
	Aluminum foil both sides	Vertical—¾" or more in width*		.46		2.17
EXTERIOR MATERIALS	Asbestos shingles			6.0		.17
	Asphalt shingles			6.5		.15
	Brick veneer	Nominal 4" thick		2.27		.44
	Built-up roofing	3/8-inch thickness		3.53		.28
	Gypsum sheathing	1/2-inch		2.82		.35
	Insulating fiberboard	25/32-inch		.42		2.37
	Lap siding, yellow pine			1.28		.78
	Plywood sheathing	5/16-inch thick		2.56		.39
	Slate	1/2-inch	10.00	20.00	.10	.05
	Stucco or stone veneer	1" thick	12.50	12.50	.08	.08
	Wood shingles			1.28		.78
	Wood, yellow pine or fir	25/32-inch	.80	1.02	1.25	.98
INSULATING MATERIALS	Aluminum foil	(See page 105)*				
	Batts, blankets or fill	Mineral, animal or veg. fiber	.27		3.70	
	Corkboard	No binder	.30		3.33	
	Insulating board	Wood or vegetable fiber	.33		3.03	
	Mineral or glass wool	Rock, slag or glass fiber	.27		3.70	
	Vermiculite	Expanded	.48		2.08	
INTERIOR MATERIALS	Composition wallboard	3/16-inch to 3/8-inch	.50		2.00	
	Gypsum plaster		3.30		.30	
	Gypsum wallboard	3/8-inch, plain or decorated		3.70		.27
	Gypsum lath and plaster	1/2-inch plaster		2.4		.42
	Metal lath and plaster	3/4-inch plaster		4.40		.23
	Plywood	3/8-inch, plain or decorated		2.12		.47
MASONRY MATERIALS	Brick, common	4" thick	5.00	1.25	.20	.80
	Brick, face	4" thick		2.30		.43
	Cement Mortar		12.00		.08	
	Clay tile, hollow	3-inch		1.28		.78
	"	4-inch		1.00		1.00
	"	6-inch		.64		1.57
	"	8-inch		.60		1.67
	"	12-inch		.40		2.50
	Concrete	Sand and gravel	12.00		.08	
	"	Cinder	4.9		.22	
	"	Pumice	2.42		.41	
	"	Vermiculite	.86		1.16	
	Concrete block, hollow	Cinder, 4-inch		1.00		1.00
	"	Cinder, 8-inch		.60		1.66
	"	Cinder, 12-inch		.53		1.88
	"	Gravel, 8-inch		1.00		1.00
	"	Gravel, 12-inch		.80		1.25
	Gypsum tile, hollow	4-inch		.46		2.18
	Gypsum, poured	12½% wood chips	1.66		.60	
	Stucco or stone		12.50		.08	
	Tile or terrazzo	For flooring	12.00		.08	
MISC.	Aluminum		1416		.0007	
	Glass	average	6		.167	
	Soil	average	7		.14	
	Steel		312		.0032	

*Refer to method outlined on page 105 or Heating, Ventilating, Air Conditioning Guide, 1951, for complete calculation details in reference to reflective materials.

Table compiled from data in Heating, Ventilating, Air Conditionion Guide, 1951, Chapters 5 and 9.

Table 2: ***U-values of common sections***

Material	Description	"U"
Window Panes	Heat Flow Horizontal	
	Single glass	1.13
	Double glass, 1" air space or greater	.53
	Double glass, 1/2" air space	.55
	Double glass, 1/4" air space	.61
	Triple glass, 1" air space or greater	.34
	Triple glass, 1/2" air space	.36
	Triple glass, 1/4" air space	.41
	Heat Flow Up	
	Single glass,	1.40
	Double glass, 1/2" air space	.66
Doors	Panel, glass or thin wood	1.13
	Solid wood, nom. 1-3/4"	.51
	Solid wood, with storm door	.30
Glass Block	Hollow, nom. 8" x 8" x 4"	.56
Concrete Floor on Ground	Any type, arbitrary value*	.10
	*Perimeter coefficient "F" is considered more accurate by many authorities: (F = Btu/hr./lineal foot/F)	
	Floating Slab—no foundation wall F = .81	
	Slab within 8" concrete block wall F = .69	
	Slab insulated at perimeter F = .55	

Material compiled from Heating, Ventilating, Air Conditioning Guide, 1951, Chapters 9 and 11.

To find Comfort Ratings, summer or winter based on inside surface temperatures

The temperature of the inside surface of a building section would be the same as the inside air temperature if it were not for the effect of the film of air clinging to this surface. This inside surface temperature is the basis for summer or winter comfort ratings and is easily determined as follows:

Find the "U" value for the construction by either of the preceding methods (on page 105). Establish the outside air temperature (t_o) from weather data or the winter design temperature (map, page 14) and the inside air temperature (t_i) from project conditions. The difference between these temperatures is expressed as ($t_i - t_o$).

The temperature of the inside surface (T_s) is then equal to the inside air temperature less the drop in temperature caused by the air film. The resistance (R_i) of the latter (.61 for walls, or .51 for heat flow up and .83 for heat flow down through floors or ceilings) is the same as the value used in the heat transmission calculations.

$$T_s = t_i - [R_i \times U \times (t_i - t_o)]$$

EXAMPLE 1: Using the wall example on page 105 (center), assume the winter outside design temperature is 0° and the inside air temperature is 70°. The U value of the wall was found to be .087, and the inside surface film resistance was .61.

Substituting in the formula:

$$T_s = 70 - [.61 \times .087 \times (70 - 0)]$$

$T_s = 70 - 3.7$ hence $T_s = 66.3$ F.

EXAMPLE 2: Again using the same wall section, assume the summer sun heat on the outside reaches 150 F. and the inside air temperature is maintained at 75 F. by cooling. Other values remain the same.

$$T_s = 75 - [.61 \times .087 \times (75 - 150)]$$

$$T_s = 75 - [.05307 \times (-75)]$$

$T_s = 75 - (-3.98)$ Since two minus signs indicate addition, then $T_s = 78.98$ F. or 79 F. for practical purposes.

To find Maximum Hourly Heat Loss or Gain through any building section or for entire building

Heating and air conditioning requirements are based on the total heat loss or gain of the entire structure. The first step is to compute this for each area involving different construction materials.

The only facts needed are (1) the U value, (2) the area, and (3) the temperature difference between the inside and outside air ($t_i - t_o$). These are simply multiplied as in this formula, in which A = area in square feet, and H_t = total heat in Btu per hour.

$$H_t = AU\,(t_i - t_o)$$

EXAMPLE: A flat roof has an area of 12,500 sq. ft., a heat transmission coeficent U of .31 Btu, and is located in Zone I where the outside air temperature is −20 F. and the inside air is kept at 75 F.

Then $H_t = 12{,}500 \times .31 \times [75 - (-20)]$

$H_t = 12{,}500 \times .31 \times 95$

$H_t = 368{,}125$ Btu per hour.

The second step, that of finding the total heat loss or gain throughout the entire building, must now be taken. This involves calculating and totaling the individual heat loss or gain through the various sections having different U values including glass areas and doors. To this sum must then be added the heat required to warm up the air used for ventilation or that entering through open doors and windows, or cracks around them. This method is outlined on page 109.

In addition, some buildings may require a factor for duct or pipe heat losses which must be added to the total heating requirements. Normally, this applies where heating ducts or pipes pass through areas that are unheated and where the heat loss represents a reduction in the heat available to the building proper.

Table 3: Infiltration through openings and cracks

Section	Type	Remarks	Infiltration in cubic feet, wind velocity, miles per hour: 5	10	15	20	25	30
WINDOWS Cubic feet per foot of crack per hour. For windows with storm sash, use ½ these values	**Double hung, wood sash** (unlocked)	Average window—not weatherstripped	7	21	39	59	80	104
		—weatherstripped	4	13	24	36	49	63
		Poorly-fitted window—not weatherstripped	27	69	111	154	199	249
		—weatherstripped	6	19	34	51	71	92
	Double hung, metal (unlocked)	Not weatherstripped	20	47	74	104	137	170
		Weatherstripped	6	19	32	46	60	76
	Rolled section, steel sash (average)	Industrial, pivoted	52	108	176	244	304	372
		Architectural, projected	20	52	88	116	152	182
		Residential, casement	14	32	52	76	100	128
		Heavy casement, projected	8	24	38	54	72	92
	Hollow metal, casement	Vertically pivoted	30	88	145	186	221	242
DOORS Cubic feet per foot of crack per hour	**Exterior door, swinging**	Well fitted door, not weatherstripped; Average door, weatherstripped	**Approx. same as DH window, poorly fitted**					
		Well fitted door, weatherstripped	**Approx. half of above DH window value**					
		Poorly fitted door	**Approx. double of above DH window value**					
		Frequently used (store) door	**Approx. 3 times above DH window value**					
DOORS Cubic feet per person per passage	**Revolving door, 72-inch** (no wind pressure)		Freely revolving			Braked		
		Infrequent usage	75			60		
		Average usage	60			50		
		Heavy usage	40			40		
	Swinging door, 36-inch (no wind pressure)	Door in one wall only	100					

Based on data from Heating, Ventilating, Air Conditioning Guide, 1951, Chapter 10.

To find Heat Required by Air Changes (infiltration and ventilation air)

The amount of air entering a building is usually dependent upon natural forces, such as wind pressures forcing air through cracks on one or two sides of a building and drawing it out on the lee side or sides. It may be augmented by deliberate ventilation through openings or by fans.

Two calculation methods are available. The more accurate one uses the data in Table 3. Measure the lineal feet of crack involved in each opening. For example, double hung windows have crackage equal to three times the width and twice the height. Each type must be computed according to its actual length of crack.

The crack length is multiplied by the appropriate value from Table 3 to arrive at the infiltration in cubic feet per hour. However, the total value must be divided by 2, because wind hits only one or two sides of a building at a time.

The second method is quite simple, but is empirical and subject to many errors under abnormal conditions. Values given in Table 4 are multiplied by the total cubic volume of the spaces to find the probable air changes in cubic feet per hour.

To convert the volume found by either method to Btu per hour, use the following formula, in which H_a is the total heat required by air changes or infiltration, in Btu per hour, and Q is the volume of air in cubic feet.

$$H_a = 0.018\ Q\ (t_i - t_o)$$

The total heat load thus found must be added to losses through walls, floors, roof and glass areas. The grand total (H_T) is the heat output required from the heating equipment.

The same method is used to compute the heating requirements of individual rooms, floors or zones.

Table 4: Infiltration based on air changes per hour

Air changes taking place under average conditions in residences, exclusive of air provided for ventilation

Kind of Room	Air Changes Per Hour: Unprotected Windows	Weatherstripped or with Storm Sash
Rooms, 1 side exposed	1	½
2 sides exposed	1½	¾
3 sides exposed	2	1
4 sides exposed	2	1
Rooms, no windows or outside doors	½ to ¾	
Entrance halls	2 to 3	
Reception halls	2	
Bath rooms	2	

Based on data from Heating, Ventilating, Air Conditioning Guide, 1951 Chapter 10.

Table 5: ***Fuel values and efficiency of heating plants***

Fuel	Unit	Approximate Fuel Value	Type of Firing	Probable Combustion Efficiency
		Btu		%
Coal	Pound	12,000	Hand fired	50 to 55
Coal	Pound	12,000	Stoker	55 to 65
Oil	Gallon	140,000	Conversion burner	55 to 65
Oil	Gallon	140,000	Oil designed unit	75 to 80
Manufactured gas	Cubic Foot	535	Conversion burner	60 to 70
Manufactured gas	Cubic Foot	535	Gas designed unit	75 to 80
Natural gas	Cubic Foot	1,000	Conversion burner	60 to 70
Natural gas	Cubic Foot	1,000	Gas designed unit	75 to 80
Steam (low pressure)	Pound	1,000	Supplied by central plant	assumed 100

To estimate Fuel Requirements and Costs for an average heating season

The following facts must be known to estimate costs, savings, and fuel requirements by the direct method outlined in this section:

H_T—total heat loss from building in Btu per hour, including heat losses due to air infiltration.

DD—Degree Days for the locality. See Degree Day map on page 14 or inquire at local weather bureau.

$t_i - t_o$ – design temperature difference used in calculation of total heat loss. See map, page 14.

F_c — Local fuel cost per unit (gallon, cu. ft., lb. or ton. Must be same unit as used in F_v, fuel value).

F_v — Fuel value per unit, in Btu, from local fuel supply or Table 5.

E— Efficiency decimal (i. e. 80% efficiency is .80) relating to efficiency of heating plant (See Table 5).

Fuel requirements in tons of coal, gallons of oil or cubic feet of gas may be estimated by the following formula.

Average annual fuel requirements =

$$\frac{H_T \times 24 \times DD}{(t_i - t_o) \times F_v \times E}$$

The average cost of fuel can be obtained by multiplying the quantity of fuel thus found by its cost, or directly by the following modification of the formula.

Average annual fuel cost =

$$\frac{H_T \times 24 \times DD \times F_c}{(t_i - t_o) \times F_v \times E}$$

Or, if you wish to compare heating costs through only a part of a building of uniform construction, such as a roof, the following formula will apply, in which A is the area in square feet.

Average annual fuel costs for a single construction =

$$\frac{AU \times 24 \times DD \times F_c}{F_v \times E}$$

All these estimates are sound for comparative purposes but may not be accurate for any specific year nor for buildings in which indoor temperatures differ materially from the usual comfort range of 68° to 72° with a night time reduction. This is obvious from the definition of Degree Days and from weather records which may show a year-to-year variation of 20% above or below the average.

To find the Economy Rating of a building section in dollars saved by insulation in an average heating season

The Economy Ratings given in the Design Tables starting on page 73 show the dollars saved in an average heating season by using insulation of the indicated thickness and effectiveness over an area of 1,000 square feet. They are based on the assumption that the heat delivered to the building costs 10 cents per Therm (100,000 Btu). The method of checking this value is given later.

The formula given above for finding the "Average annual fuel costs for a single construction" is used to find the Economy Rating of that section, except that the area A is assumed to be 1,000 square feet and the cost of fuel is 10 cents per 100,000 Btu or \$1.00 per million Btu actually delivered to the building. With these assumptions the formula becomes:

$$\text{Economy Rating} = \frac{1000 \times U_s \times 24 \times DD \times \$1.00}{1{,}000{,}000}$$

$$= \$.024\ U_s \times DD$$

The value U_s is the Btu saved by insulation and is found by subtracting the U value of the insulated section from the U value for the same section without insulation.

However, this Economy Rating assumes a fuel cost that is fairly average but may not represent your local condition. To find the cost of your local fuel in "effective" Therms (delivered by the heating plant to the building), use this formula:

Cost of fuel per effective Therm =

$$\frac{100{,}000\ \ F_c}{F_v \times E}$$

The result will be in the same units, cents or dollars, used in pricing the fuel.

EXAMPLES: Assume oil costing 12¢ per gallon and containing 140,000 Btu per gallon is burned at 80% efficiency.

Cost of fuel per effective Therm =

$$\frac{100{,}000 \times 12}{140{,}000 \times .80} = \frac{1{,}200{,}000}{112{,}000} = 10.7 \text{ cents}$$

If the 12 cents had been expressed in dollars as \$.12 the answer would be \$.107.

Assume you are using bituminous coal which contains 12,000 Btu per pound (or 24,000,000 Btu per ton), costs $22.00 per ton and is burned in a stoker-fired domestic unit operating at 60% efficiency.

Cost of fuel per effective Therm =

$$\frac{100{,}000 \times 22.00}{24{,}000{,}000 \times .60} = \frac{2{,}200{,}000}{14{,}400{,}000}$$

$= \$.153$ or 15.3 cents.

The Economy Rating is intended only for comparisons between different constructions and seldom needs to be calculated.

For practical purposes, it is thus easier to work directly from one of the appropriate formulas on page 110 using actual project areas and local fuel costs.

If you want the dollars saved in an average heating season by the use of insulation, keep track of the difference in U values between insulated and uninsulated constructions. Whenever you substitute this difference, U_s, in place of U in any of the formulas you find the *savings* due to the use of insulation.

To find Air Conditioning and Cooling Loads use the services of an expert and start during preliminary design stages

The compilation of summer cooling loads involves the same principles as in determining heating loads but adds new factors such as moisture heat load (latent heat), solar heat gain, heat from occupants, lights and equipment, and time lag due to the heat capacity of the structure.

It also involves a rare ingredient not found in tables—the mature judgment of an expert in air conditioning practices.

Because of these facts, no data are presented here on the calculation of air conditioning or refrigeration loads. The Heating, Ventilating, Air Conditioning Guide published by the American Society of Heating and Ventilating Engineers is the standard authority on this subject (as it is on heating and insulation), but its use calls for training and experience.

If a new building is to be designed as an air-conditioned structure, it is wise to consult an expert in this field even before the orientation and fenestration of the structure is fixed. The angle of the building in relation to the path of the sun, the size of the glass areas and the use of sun-shading devices or special heat-absorbing glasses can vary the total load, (and subsequent operating cost) through a very wide range.

For general design purposes it is sufficient to note that air cooling costs several times as much as air heating on a unit basis of volume and time, and that the insulation installed to conserve heat in winter works equally well to reduce heat gain and cooling costs in the summer.

Tests, Tolerances and Accuracy

Experience indicates that values calculated by the methods described in these pages are reliable for comparative purposes and reasonably accurate for predicting average heating loads. Nevertheless the accuracy attained is often due to a balancing of variables and it is well to understand how many of them are involved. On occasion these variables may combine to throw the results 20% or more above or below actual performance.

1. Weather conditions are highly variable. Actual design temperatures and Degree Days for a given year in a given locality may vary 20% from the average which is based on years of accumulated data.

2. Building products are subject to manufacturing tolerances which may be small for some precision materials or quite wide for rough materials. Since thickness is a direct function of conductance, thickness variations may significantly affect calculations. For example, lumber is measured in nominal dimensions: a one inch (nominal) board is usually 25/32″ thick or nearly 22% less than nominal. A 2″ x 4″ stud is actually 1-5/8″ x 3-5/8″ thick, off 9.4%. Commercial standards for mineral wool allow a quarter inch variation in batt or blanket thickness, so that a 3″ batt is commercially acceptable if 2-3/4″ thick. This is a reduction of 9.6%. Similarly, densities are often a factor in the conductance of heat and are subject to reasonable tolerances. Fortunately these variations have a relatively minor influence in calculated results.

3. Tests for thermal properties are also subject to tolerances. A well operated thermal testing laboratory should agree with the National Bureau of Standards in conductivity (k) measurements within plus or minus .005 Btu or approximately 1½% for a material whose "k" is 0.30 when they use the guarded hot plate as prescribed in ASTM C-177. Nevertheless, well recognized testing laboratories have difficulty keeping within these limits. As a result of studies currently under way, it is believed that a tolerance of plus or minus .01 Btu or approximately 3% will be recognized as acceptable.

4. Published test values, however, are not always made under the same testing standards, either of apparatus or techniques. These have evolved during the last fifteen years, yet some published values have remained unchanged for twenty years or longer. It is therefore probable that some test values are out of line with values that would be found by currently accepted methods by as much as 20%.

In the light of these four factors alone—weather, manufacturing tolerances, testing tolerances and obsolescence of test data—it is obvious that the calculated thermal properties of building sections should be used with an understanding of their limitations. Other factors also are involved, particularly workmanship in the installation of insulating materials and vapor barriers, but they are probably more significant in relation to vapor control than to heat transfer calculations.

Projects which involve heat control and vapor control as major considerations should be designed with a reasonable factor of safety. None is required in buildings intended for normal occupancies.

Slide rule calculations are justified in thermal work and have been used throughout this book. While slide rules can be reliably read to three significant figures, it should be noted that conductance values are customarily limited to two decimal places when above .10 Btu and to three places below .10 (as .097 Btu). Technically no value derived from these figures is accurate beyond two significant figures, but it is customary practice to accept slide rule results to three or sometimes four significant figures.

DESIGN CALCULATIONS:

For vapor control

The principles of vapor movement and vapor control in buildings are firmly established. The application of these principles has been less well understood by the industry, even though they were independently presented by L. V. Teesdale and F. A. Rowley in 1937-38. Since then there has been emerging some agreement on methods of predicting the probability of condensation within building sections by calculations approximating those used in heat transfer, but these methods require more complete data on the permeance of building materials than have yet been accumulated.

In this field, therefore, it is reasonable to expect substantial advances in technical knowledge and calculation methods in the coming years. To keep this manual within the province of practical daily use, without resorting to complex mathematics and advanced technology, it is necessary to limit the design calculations to those essential to general design work. When unusual problems arise, or the importance of vapor control exceeds other design considerations, reference should be made to the Heating, Ventilating, Air Conditioning Guide published annually by ASHVE, or to consulting engineers and research authorities who are familiar with this subject.

Only one simple calculation is needed for most building design purposes. It establishes the occupancy-moisture rating of the building, based on outdoor climate, the probable indoor moisture level that will prevail in cold weather, the heat transmission coefficient of the building section and the proposed location of a vapor barrier in the construction. This calculation is described below.

It has been established earlier that if a vapor barrier of perfect effectiveness is properly located close to the warm side of a construction, no condensation can occur within that construction. But it is impractical to construct a barrier having no permeance whatever. Therefore it is often desirable to analyze what may happen to the vapor that leaks through the barrier, to approximately forecast the conditions under which condensation of troublesome magnitude might develop. A method of making such an analysis is outlined on page 113.

To find the Occupancy-Moisture Rating of a building section

This rating is essentially the highest relative humidity that can be maintained within a building of given construction without inducing condensation to form on the warm-side face of a vapor barrier embodied in the construction under specified temperature conditions.

It is here presumed that a vapor barrier can be made sufficiently effective in practice so that the likelihood of condensation resulting from leakage through the barrier will be negligible in magnitude, frequency or duration.

Facts needed are: (1) Inside and outside design temperature (t_i and t_o), (2) the thermal resistance of the materials, surface films and air spaces in the building section, and (3) the relative humidity anticipated in the indoor air during periods when the design temperatures will prevail.

Prepare a tabulation of the construction assembly in the same manner as for calculating the U value, listing all elements in their proper order from outside to inside. Find the total resistance R by adding the individual resistances. Also find the sum of the resistances of the materials and inside surface film that lie between the vapor barrier (or any point x at which the temperature is desired) and the inside air. Call this sum R_x. Then substitute the values in this formula:

$$\text{Temp. at point x} = t_i - \frac{R_x}{R}(t_i - t_o)$$

EXAMPLE: Find the temperature at the vapor barrier (point x) in the construction illustrated, assuming the inside air temperature, t_i, is 70° F. and the outside air temperature, t_o, is 0° F. (See calculation at the right.)

From Table 6 find the vapor pressure of saturated air at the indoor design temperature, also at the temperature found for the vapor barrier. Divide the lower pressure by the higher to get the percent of saturaturation of the indoor air which corresponds to saturation at the vapor barrier. *This is the relative humidity permissible within the room,* below which condensation will not occur at the vapor barrier. It is also the Occupancy-Moisture Rating.

	Resistance	Resistance, to vapor barrier
$1/f_o$, outside air film, 15 mph wind	.17	—
face brick, 4"	.43	—
common brick 4"	.80	—
air space (over ¾")	91	—
insulation, 2", with vapor barrier on warm face (Point X)	7.40	—
plywood, ⅜"	.47	.47
$1/f_i$, inside air film, still air	.61	.61
R total	10.79	1.08

temperature at vapor barrier $= 70 - \frac{1.08}{10.79}(70-0) = 63°$F

Continuing the example above: The vapor pressure of saturated air at 63° F. is .5800 and at 70° is .7392. The permissible relative humidity is then:

$$\frac{.5800}{.7392} = .78 \text{ or } 78\%$$

The Occupancy-Moisture rating is 78%.

Table 6: ***Pressure of water vapor at saturation***

Temperature (F)	Pressure (in. Hg)	Temperature (F)	Pressure (in. Hg)	Temperature (F)	Pressure (in. Hg)
−20	0.01259	20	0.1027	60	0.5216
−19	0.01333	21	0.1078	61	0.5405
−18	0.01410	22	0.1130	62	0.5599
−17	0.01493	23	0.1186	63	0.5800
−16	0.01579	24	0.1243	64	0.6007
−15	0.01670	25	0.1303	65	0.6221
−14	0.01766	26	0.1366	66	0.6441
−13	0.01867	27	0.1431	67	0.6668
−12	0.01974	28	0.1500	68	0.6902
−11	0.02086	29	0.1571	69	0.7143
−10	0.02203	30	0.1645	70	0.7392
− 9	0.02327	31	0.1723	71	0.7648
− 8	0.02457	32	0.1803	72	0.7911
− 7	0.02594	33	0.1878	73	0.8183
− 6	0.02737	34	0.1955	74	0.8463
− 5	0.02888	35	0.2034	75	0.8751
− 4	0.03047	36	0.2117	76	0.9047
− 3	0.03213	37	0.2202	77	0.9352
− 2	0.03388	38	0.2290	78	0.9667
− 1	0.03572	39	0.2382	79	0.9990
0	0.03764	40	0.2477	80	1.0323
1	0.03966	41	0.2575	81	1.0665
2	0.04178	42	0.2676	82	1.1017
3	0.04400	43	0.2781	83	1.1380
4	0.04633	44	0.2890	84	1.1752
5	0.04878	45	0.3002	85	1.2136
6	0.05134	46	0.3119	86	1.2530
7	0.05402	47	0.3239	87	1.2935
8	0.05683	48	0.3363	88	1.3351
9	0.05977	49	0.3491	89	1.3779
10	0.06286	50	0.3624	90	1.4219
11	0.06608	51	0.3761	91	1.4671
12	0.06946	52	0.3903	92	1.5136
13	0.07300	53	0.4049	93	1.5613
14	0.07669	54	0.4200	94	1.6103
15	0.08056	55	0.4356	95	1.6607
16	0.08461	56	0.4518	96	1.7124
17	0.08884	57	0.4684	97	1.7655
18	0.09326	58	0.4856	98	1.8200
19	0.09789	59	0.5033	99	1.8759

To analyze a building section for potential condensation

When building sections are known to contain no vapor barrier, or relatively imperfect barriers, or have cold-side materials of comparatively high resistance to vapor, it is often desirable to make an analysis of the assembly, without involved calculations, to see if it is likely that condensation will occur and what can be done, design-wise, to forestall this possibility.

In Table 7 are given the permeances of a variety of building materials, tested by different authorities and often by different methods that do not produce equivalent results. Although obviously lacking in coverage and consistency, these values will suffice for making an approximate analysis of building sections by the following simplified method:

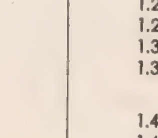
List the materials, without surface films or air spaces, in the order of their appearance in the wall, beginning with the inside surface material and working outwardly.

Against each product list the permeance given in Table 7, or a more accurate value if available from tests or manufacturers' data. Where a range of values is given in the table, take an average or use your judgment based on the character of the particular material you propose to use.

Start at the top of the list and note any material that has *less* permeance than the materials above it on the list. At that point the possibility exists that vapor leaking through the first material may condense on the second, provided the dew-point is reached and the movement is considerable. In that event, an effort should be made to provide ventilation through the cold side material, or the design modified to eliminate it. If the leakage is slight (or the difference in permeance small) then judgment should be used to estimate, by the severity of the climate and the duration of cold periods, whether condensation during these transient conditions is likely to be sufficiently troublesome to warrant either ventilation or a change in design.

The following examples may clarify this method:

EXAMPLE 1.



	Est. Permeance
plaster, painted 3 coats	3.7
vapor barrier	1.0 (lowest)
insulation	29.0
wood sheathing	2.9
4" brick veneer	1.1 (next)

In this example the vapor barrier transmits 1 grain of moisture per square foot

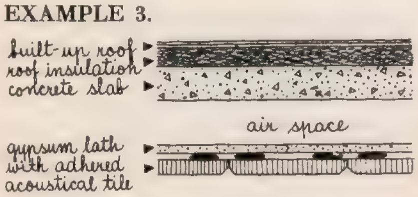
per hour for each unit of vapor pressure difference and nothing else transmits less. However the cold brick veneer is nearly as low in permeance, hence it is advisable to make certain that the vapor barrier is expertly installed, with all openings at pipes, outlet boxes or joints carefully fitted or sealed. Alternatively, the brick veneer may have open mortar joints near the top and bottom to serve both as weep holes and as vapor release openings. They would also ventilate the wall and help reduce sun heat in summer.

EXAMPLE 2.

	Est. Permeance
wall paper on plaster	5.0 to 10.0
furred space	—
concrete block	2.0
brick veneer (lowest)	1.1

In this case vapor would easily pass through the interior finish, be slowed up by the concrete block and nearly stopped by the brick veneer. Unless this design is radically improved, the masonry will become saturated and may cause serious water stains or apparent "leaks" in cold weather.

EXAMPLE 3.



	Est. Permeance
acoustical tile (mineral wool)	29.
gypsum lath (suspended)	15.
concrete slab (based on block)	2.0
roof insulation	29.
roofing, built-up	.15 (lowest)

The first resistance to vapor occurs at the concrete roof slab, which would be fairly cool because of the protection afforded by the insulating value of the acoustical tile and the air space formed by the suspended ceiling. In all probability moisture would condense on the surface under high humidity conditions, but it is certain that some of the vapor would continue to move through the slab, the insulation above, and then condense on the under side of the cold roofing. It would flow back, as water, saturating the insulation, then the deck, and would eventually drip to the ceiling below. This condition might not be observed for a long time, because the gypsum lath and the acoustical tile would first soak up the water dripping from above. Nevertheless, the condition is hazardous.

Table 7: *Vapor permeance of building materials*

Permeance values in grains per square foot per hour per inch of mercury pressure.

Material	Vapor Permeance (P - Perms)	Vapor Resistance (1/P - Rep)
EXTERIOR MATERIALS		
Brick masonry, 4 in.	1.1	0.91
Concrete block, laid up	2.0	0.50
Paint film (varies with age)	3.4	0.29
Pine lap siding	4.9	0.20
Plywood, 3/8-in. exterior grade, 3 coats outside white paint	0.17	5.88
Plywood, (plyscord) 5/16-in., no finish	2.13	0.47
BUILDING PAPERS		
Waterproof paper, light weight slater's felt	49.1	0.02
Sheathing paper, asphalt impregnated, glossy	0.17 - 2.05	0.49 - 5.88
Roll roofing, smooth, 40 - 65 lb. per 108 sq. ft.	0.13 - 0.17	5.88 - 7.70
SHEATHING		
Fir sheathing, 3/4-inch	2.9	0.34
Insulating lath and sheathing, board type	25.7 - 34.3	0.03 - 0.04
Insulating sheathing, surface-coated	3.03 - 4.36	0.23 - 0.33
Plywood, 1/2-in., 5-ply Douglas fir	2.7	0.37
INTERIOR FINISHES		
Gypsum lath with aluminum foil backing	0.09 - 0.39	2.56 - 11.5
Plaster base and plaster, 3/4"	14.7	0.08
Plaster, wood lath	11.0	0.09
Plaster, fiberboard or gypsum lath	19.7 - 20.6	0.05
Plaster, 3 coats of lead and oil	3.68 - 3.84	0.26 - 0.27
Plaster, 2 coats of aluminum paint	1.15	0.87
Plywood, 2 coats asphalt paint	0.43	2.32
Plywood, 2 coats aluminum paint	1.29	0.78
Fiberboard, 1 surface asphalt coated	3.9 - 8.5	.12 - .26
Wood, spruce or pine, 1/2-inch	1.7 - 2.0	.50 - .59
Hard fiberboard	4.7 - 10	.10 - .21
INSULATING MATERIALS		
Mineral wool, unprotected	29.07	0.03
Insulating cork blocks, 1-in.	6.19	0.16
Foil-surfaced reflective insulation, double-faced	0.08 - 0.13	7.70 - 12.5
VAPOR BARRIER PAPERS		
Duplex or laminated papers, 30-30-30	1.37 - 2.58	0.39 - 0.73
Duplex or laminated papers, 30-60-30	0.52 - 0.86	1.16 - 1.94
Duplex paper, coated with metallic oxides	0.52 - 1.29	0.77 - 1.94
Insulation backup paper, treated	0.86 - 3.42	0.29 - 1.16

Compiled from data by L. V. Teesdale, L. G. Miller, J. D. Babbitt and Forest Products Laboratory, U. S. D. A

Correctives are obvious. A vapor barrier on the roof deck, with sufficient insulation above to keep it above the dew-point temperature of the interior air is the first recommendation. Alternatives include a vapor barrier on the back of the gypsum lath, with insulation resting on the lath and adequate venting of the plenum to the outside air; or a combination of a vapor barrier on the roof deck with enough heat added in the plenum to reduce the amount of insulation needed to keep the vapor barrier warm.

Alternate Method of Analysis. A more precise method of determining condensation possibilities can be used where vapor permeance values are known for all the materials used in the construction. This method should be used when greater accuracy is desired and where actual testing of a panel is not warranted.

First, find the vapor pressure on both sides of the section and at each possible condensation point (x) within the structure. The latter can be determined by the following formula:

$$P_x = P_i - \frac{\text{Rep (i to x)}}{\text{Rep (total)}} \times (P_i - P_o)$$

where: P_x = vapor pressure at chosen point x.
P_i = vapor pressure inside
P_o = vapor pressure outside
Rep (i to x) = sum of vapor resistances from inside surface to point x.
Rep (total) = total vapor resistance of section.

Second, find in Table 6 the vapor pressure nearest to that determined for each point x, and note the corresponding temperature. This will be the temperature at which air adjacent to point x would be saturated.

Then, calculate the actual temperatures at each of the points chosen. Use procedure outlined on page 112.

Analysis: Where the actual temperature at any point x is found to be below the *saturation* temperature determined for the same point, condensation can occur. If necessary, the amount of condensation that will accumulate per hour can be gauged by the amount of vapor pressure difference and the permeance of the materials on the warm side of point x.

Analyze the cricital areas for possible vapor relief, i.e., ventilation openings, duration of exposure, water absorption capacity of surfaces, and permissible amount of condensation without danger of damage to adjoining materials.

DESIGN CALCULATIONS:

For structural ventilation of insulated spaces

Most of the research in ventilation as a means of relieving condensation in building sections, without reliance upon superior vapor barriers, has been related to dwellings. Test houses, necessarily of limited dimensions, have been erected within large test chambers but comparatively little has been done to evaluate venting requirements in loft spaces of large structures, or in air-cooled walls.

Until such research has been done, all practices must be founded upon the available data. So far as has been observed and reported, the extension of the residential practices to larger buildings has proved satisfactory.

Practically no research has been accomplished in the field of roof and wall ventilation as related to increased summer comfort indoors and reduced solar heat loads on air conditioning equipment. Actual buildings that have been erected employing air cooled walls or roofs, or both, have performed well.

Since deductive reasoning must be applied to extend known data into untested areas, the basis for this reasoning is summarized for reference on page 116.

To find size of vents required for natural vapor ventilation of attics or lofts

Compute the area of insulation, measured from wall to wall at the attic or loft level, in square feet.

From the Recommended Practices in the table on page 63, determine the ratio of net vent area to insulated area. Divide the insulated area by the ratio selected to find the net free area required in vents.

From Table 8 determine the gross area equivalent to a net free area when louvers or screens are used, and multiply the required area by the selected factor. This is the gross area required in openings.

Study the attic layout and the exterior elevations and locate vent openings at points most likely to assure uniform movement of air throughout the attic. Make the several vents of such size that their total will equal or exceed the gross vent area required.

Table 8: ***Net and gross area of vent openings***

Type of screen or louvers	For Gross Area multiply net area by —
1/4″ mesh hardware cloth only (Minimum for crawl spaces)	1
1/8″ mesh screen only (Minimum for attic and loft spaces)	1¼
1/16″ mesh insect screen only	2
Louvers and 1/4″ mesh hardware cloth	2
Louvers and 1/8″ mesh screen	2¼
Louvers and 1/16″ mesh insect screen	3

EXAMPLE: A hip-roofed building has an insulated area of 2,800 square feet. From the table on page 63 a vent ratio of 1 to 600 is required at the ridge and 1 to 600 at the eaves. Then $\frac{2800}{600} = 4\frac{2}{3}$ sq. ft. of net free area is required in each location.

It is decided to extend the ridge line at the jack rafters to provide two louvered and insect-screened vents in small gables. From Table 8 we find the gross area of the opening should be 3 times the required net area.

Hence the ridge gable openings should total 4-2/3 x 3 = 14 square feet, or 7 sq. feet in each louver.

At the eaves, it is decided to use continuous slit vents between the fascia board and the soffit. The slits will be screened only; hence from Table 8 the gross area should be twice the net area, or 4-2/3 x 2 = 9-1/3 square feet. The perimeter of the roof is measured and found to be 230 lineal feet. If the slit were one inch wide, each 12 linear feet would provide one square foot of area or 230 = 19.1 sq. feet in total. A slot ½″ wide would therefore serve, but shorter slots 1 inch wide would give better performance through less air friction.

To estimate the capacity required in gravity or mechanical roof ventilators

When sidewall vents are impractical and all venting must be done through the roof, the design should provide monitors or ventilators for air intake into the loft plus monitors, stacks, gravity ventilators or mechanical fans or blowers to remove the air and its vapor.

Compute the volume of space in the attic or loft, in cubic feet. Where the ceiling insulation is not protected by a vapor barrier, or where vapor leakage through stair wells, elevator shafts or similar openings indicate a high rate of vapor movement, assume not less than 3 air changes per hour are required for vapor relief only. Buildings with high-moisture occupancies may require substantially more changes. When a vapor barrier is provided and occupancy is "normal" or "dry" it may be assumed that one air change per hour will serve adequately.

Multiply the volume of the loft space in cubic feet by the number of air changes per hour and divide by 60 minutes, to find the air volume to be removed per minute through ventilators or by fans.

Consult manufacturers' catalogs for capacities of appropriate units and provide both intake and exhaust ventilators of the required capacity. Locate them for uniform distribution of air movement. When a grille or louver opening is used as an air intake, base its size on an air velocity through it of 750 feet per minute; thus, air required in cubic feet per minute divided by 750 would equal the net free area required in square feet. FHA requires a minimum vent ratio of 1 to 100 when attic fans are used, or the net area recommended by the Propeller Fan Manufacturer's Associations' publication "Residential Ventilation Guide". Net area must be adjusted by Table 8 to get the gross area of the opening.

To estimate air movement desirable for summer comfort under attics or lofts

Until more specific test data are available (as noted below) it may be assumed that doubling or tripling the air movement required in winter for vapor release is desirable for summer comfort.

Where fans can be provided, night air cooling practices may be adopted, providing anywhere from 10 to 60 air changes per hour, based on the volume of the attic or loft. Vent openings must be large enough to handle this air movement. Attic fans can often be installed with trapdoors so that air is changed in the attic during the daytime and in the living areas during the cooler night period.

Sources of data on ventilation used in these calculations

Ventilation requirements for natural air movement from the attics of dwellings (by wind movement and gravity flow or chimney effect) are generally expressed as the free area of vent openings in relation to the area of the insulation immediately below. Ratios of 1 sq. foot of free vent area to 300 sq. feet of insulated area or 1 to 150 or 1 to 600 are most frequently used. There seems to be no reason to change these ratios for larger areas provided vent openings can be spaced at such intervals as to assure reasonably uniform air and vapor movement. However, it seems probable that commercial, institutional or industrial buildings of large size, or those located in congested built-up areas where adjacent buildings prevent the location of vents on all sides, may require larger vents or even mechanical auxiliary ventilation.

Such auxiliary ventilation for vapor relief purposes is calculated on the basis of observations by Rowley, Algren and Lund (Bulletin No. 18, University of Minnesota Engineering Experiment Station "Condensation of Moisture and Its Relation to Building Construction and Operation", 1941) to the effect that when a fan moved air from the attic of their test house at 35 cfm, condensation was found, but when the air movement was stepped up to 105 cfm, no condensation developed. In the loft of a flat-roofed test house, air flow through special ventilators ranged from 90 to 130 feet per minute, with apparently satisfactory results.

Again, Rowley, Lajoy and Erickson in Bulletin No. 26, (1947) on "Moisture and Temperature Control in Buildings Using Structural Insulating Board" reported that ventilation up to 1.85 changes per hour did not correct vapor leakage through ceilings with no vapor barrier and a loosely fitting attic door, but that 1.25 changes per hour were adequate when gross leakage through the door was eliminated; and that addition of a vapor resistant treatment on the ceiling plaster reduced the required air wash to .75 changes per hour.

From these limited but competent investigations we have assumed that fan or blower design should be based on changing the air in a loft space at least 2 to 3 times an hour when no vapor barrier is used and the indoor relative humidity is around 40% with 0° F. to -10° F. outdoors, and from there down to perhaps .50 change per hour if a reasonably good vapor barrier is present.

In the field of summer ventilation of lofts and attics for comfort, there is even less data to draw upon. We have started with two observations: One is that when the body of a building is protected with insulation for winter conditions, there is no theoretical limit to the amount of natural ventilation that can be provided under a roof. The only practical limit is that overhangs, louvers or ventilators must not admit wind-driven rain (or snow in winter).

The second is the experience that has been gained with night air cooling with attic fans. W. H. Badgett, in Bulletin No. 7 (1940) of the Agricultural and Machanical College of Texas "The Installation and Use of Attic Fans" recommends equipment capable of making a complete air change every minute (60 changes per hour) for the Gulf Coast and Texas areas. This rate seems enormous to persons living in a less humid climate, where more than 30 air changes per hour would create sufficient breeze within a building to cause complaints. Nevertheless, if such volumes are found desirable to remove the absorbed heat from furniture, floors, walls and ceilings during the night, they would by reasonably appropriate to remove solar heat from the under side of roofs over lofts or attics.

On these several assumptions the calculations presented on the preceding page were developed for use until better-founded data become available.

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